FINAL REPORT

Nanotechnology for the Solid Waste Reduction of Military Food Packaging

ESTCP Project WP-200816

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14. ABSTRACT
This effort demonstrates and validates nanocomposite packaging for military rations to decrease the amount of solid waste for the military. This investigation focused on the Meal Bag for the Meal, Ready-to-Eat (MRE), the non-retort food pouch for the MRE and the retort pouch for the MRE. These nanocomposite packaging systems were evaluated to ensure that all performance objectives were met in terms of shelf life, rough handling, and storage. Tests conducted included storage studies, insect infestation, recyclability, and transportation studies.

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ACRONYMS

- Accel - Acceleration
- AGL – Above Ground Level
- BON – Biaxially Oriented Nylon
- CDS – Container Delivery System
- CID – Commercial Item Description
- C-130 – Cargo Aircraft
- CFD – Combat Feeding Directorate
- CLT- Central Location Testing
- CFREP - Combat Feeding Research Engineering Program
- CPP – Cast Polypropylene
- CST – Central Standard Time
- DOD – Department of Defense
- DLA – Defense Logistics Agency
- DSC – Differential Scanning Calorimetry
- EF-XL_{15} = EVAL 15 micron bi-ax 32 mol% EVOH film
- ESTCP – Environmental Security Technology Certification Program
- FIRIP - Fielded Individual Ration Improvement Program
- FGRIP - Fielded Group Ration Improvement Program
- Flake – plastic ground for recycling
- FIRIP - Fielded Individual Ration Improvement Program
- G – Gravitational Force, unit of acceleration
- GC/MS – Gas chromatograph / mass spectroscopy
- GL = Toppan GL-ARH (inorganic barrier coated PET)
- GLP – Good Laboratory Practices
- HASP – Health and Safety Plan
- HDPE – High Density Polyethylene
- HV – High Velocity
- ILS – Inter laboratory Study
- JSORF - Joint Service Operational Rations Forum
- K-C = KURARISTER C
- K-N = KURARISTER N
- LDPE – Low Density Polyethylene
- LLDPE – Linear low density polyethylene
- LV – Low Velocity
- MBL Moses BioLogic
- MF225 = Rohm and Haas Mor Free 225 + C33 solventless retort grade adhesive
- MRE – Meal, Ready-to-Eat
- Mbar – Millibar, unit of air pressure
- Nano - Nanocomposite
- NSRDEC – U.S. Army Natick Soldier Research, Development and Engineering Center
- ON – Oriented Nylon
- OTR – Oxygen Transmission Rate
- PE -Polyethylene

- PCR – Product Contract Requirement
- PET – Polyethylene Terephthalate
- RS – Ring Slot
- SD – Standard Deviation
- SERDP – Strategic Environmental Research and Development Program (SERDP)
- SPME - Solid phase microextraction
- SPSS - Statistical Package for Social Sciences
- SOP – Standard Operating Procedure
- TAPPI – Technical Association for Pulp and Paper Industry
- TISA – Troop Issue Subsistence Activity
- TTC – Texture Technologies Corporation
- USDA – United Stated Department of Agriculture
- WVTR – Water Vapor Transmission Rate
- YPG – Yuma Proving Ground
- %RH – Percentage of relative humidity, unit of humidity

ACKNOWLEDGEMENTS

The Principal Investigators (PIs) acknowledge the Environmental Security Technology Certification Program (ESTCP) as well as all the collaborators and partners in this project. This demonstration/validation program was not only successful for nanocomposite packaging, but a rewarding and valuable experience for the Principal Investigators. The PIs began exploring nanocomposites with basic research over 10 years ago and ultimately transitioned the technology to the ESTCP program. The nanocomposite effort began with support from a 6.1 Environmental Quality Basic Research Program that transitioned to a 6.2 Strategic Environmental Research and Development Program, then to a 6.3 Army Research Laboratory Pollution Prevention Program, then finally to the ESTCP. The authors are truly grateful for all the funding and support for 6.1 to 6.4 work utilizing nanotechnology packaging. The PIs have been dedicated to these efforts and it is anticipated that this technology will be used someday by the WarFighter.

In particular, the PIs thank Mr. Bruce Sartwell, Dr. John Hall, and Dr. Jeffrey Marqusee as well as their support teams and their review boards whom have given valuable input and feedback throughout the program. Also, the PIs are forever grateful for the financial support of the project from ESTCP.

In addition, there are many scientists and engineers who participated in this effort and formed a dedicated team. Each member has brought their own expertise to execute their portion of the demonstration/validation plan. The Advanced Materials Engineering Team at the U.S. Army Natick Research, Development and Engineering Center (NSRDEC) have all contributed to this project especially Mr. Jason Niedzwiecki, Dr. Christopher Thellen, Ms. Danielle Froio, Ms. Sarah Cheney, Mr. Christopher Hope and Mr. Jacob Boone. NSRDEC thanks Kuraray America Inc. for the nanocomposite food pouches; Cadillac Products Packaging Company for the nanocomposite meal bags; AmeriQual especially, Ms Robin Altmeyer, for the assembly, quality control testing of the rations, and shipping of the pallets to a variety of locations. The team thanks Ms. Claire Lee and Ms. Nicole Favreau of Combat Feeding Directorate who performed the microbial evaluation and lipid oxidation, respectively. The team extends gratitude to Mr. Alan Wright and his team for the sensory testing and evaluations. The team is thankful to the air drop team, at NSRDEC which consisted of Richard Benny, Brian Bagdonovitch, and Dale Tabor. The team appreciates participants of the field study evaluation, Ms. Wendy Johnson, Mr. Dan Harshman, Mr. Gregory Pigeon and Mr. Scott Winroth. The team also acknowledges Fort Richardson and Fort Bliss for the transportation and distribution studies. Jade Vardeman of Moses Biologic, is also recognized for conducting the insect infestations studies, and Pira International for their distribution laboratory testing. Everyone worked extremely hard in support of this ESTCP effort and we are forever indebted to each person for their talents and dedication.

EXECUTIVE SUMMARY

This effort demonstrates and validates nanocomposite packaging for military rations to decrease the amount of solid waste for the military. This investigation focused on the Meal Bag for the Meal, Ready-to-Eat (MRE), the non-retort food pouch for the MRE and the retort pouch for the MRE. These nanocomposite packaging systems were evaluated to ensure that all performance objectives were met in terms of shelf life, rough handling, and storage. Tests conducted included storage studies, insect infestation, recyclability, and transportation studies. The non-retort food item chosen was pretzels and the retort food item was vegetarian penne pasta. Storage studies were conducted for three years at 40, 80, 100 and 120^{o}F. Storage study testing consisted of: sensory analysis, oxygen concentration, hexanal analysis, and microbiological analysis.

The nanocomposite Meal Bag was fabricated from the same base resin as the existing control bag, but 7.5% nanocomposite was added for improved thermal and barrier properties. The thickness of the nanocomposite Meal Bags was 7 mil versus 11 mil for the control bag. After testing and evaluation, it was determined that the performance objectives for the Meal Bag were all met.

The nanocomposite Meal Bag's integrity in comparison to the control Meal Bag was in the same acceptable range. This was measured by determining the seal strength at the top and bottom seal. The Meal Bags were also rough handled at different temperatures using the tests corresponding to the military specification requirements and these met the success criteria. Rough handling of the pallet load was also performed and minimal defects were found in both the control and nanocomposite Meal Bags. Another performance objective that the Meal Bags met was resistance to insect infestation. The control and nanocomposite Meal Bags were exposed to a variety of insects typically encountered during storage and samples were examined at predetermined time periods. There was no more than 20% failure for the Meal Bags.

One of the performance objectives was to assure recyclability of the Meal Bag. This was demonstrated in the laboratory by remelting and reprocessing of the polymer nanocomposite with other virgin polymer. Also, the recycling company, TREX, did confirm that the Meal Bags could be utilized in their recycling facility. TREX conducted similar experiments that were performed at NSRDEC, but also addressed color, rheology and mixing of the Meal Bag material with TREX's regrind. The weight savings, reduction of solid waste and decrease in base resin are all approximately 30%, however the addition of nanoparticles results in an increase in cost to the formulation.

The nanocomposite non-retort pouch which contains a 3 layer polymeric structure with an inner layer containing nanoparticles was compared in this demonstration and validation program to the control non-retort pouch which utilizes an aluminum foil layer for the barrier with polymer layers. The recyclability of the pouch was not met with the nanocomposite structure as there is too wide of a melt temperature range for it to be recycled. In-house and external studies with TREX have shown that it can be remelted, but would not work with industrial recycling film equipment since there are too many higher temperature plastics in the structure. The melting temperature window of the nanocomposite pouch does not fit the recycling temperatures.

The oxygen concentration was analyzed at each storage study pull and showed to be in the same value for the extent of the study. The lipid oxidation was also checked at each time period during the storage study and there was no considerable difference in hexanal levels for both pouches. The shelf life of three years was demonstrated and validated by the sensory study for accelerated and long term storage. The insect infestation studies proved that the nanocomposite non-retort pouch did not have any failures after 12 weeks, passing the success criteria. The integrity of the pouches was validated in the laboratory at the case level and pallet size level meeting the performance objective. For the sensory study beyond 2 years, it appeared that the pretzels exhibited some staling and that the water content increased primarily at the 40^{o}C temperature only.

For the retort pouch a 4 layer polymeric structure was used that had another protective layer for oxygen barrier incorporated into the outer layer and it contained a nanocomposite layer.
All of the same tests were conducted with the control and nanocomposite retort pouches as was performed with the non-retort samples, except a microbial evaluation was added. All the other tests passed except for the recyclability. The microbial evaluation was conducted at time 0, and for every storage interval that a sensory test was conducted during both the accelerated and long term storage. The microbial evaluation was performed with 5 retort pouches of each sample and all samples were acceptable with no food safety issues. The storage study also was a success with all samples comparing to the hedonic results of the control samples. During recyclability testing, similar issues with melt temperatures of various polymers were encountered as with the non-retort pouch.

The ration packaging system performance objectives were all successful. A critical performance objective was for soldier acceptance of the packaging, which was demonstrated by a field study survey with approximately 100 soldiers. The acceptability of the packaging was comparable with the controls.

The reduction of solid waste was contributed by the decrease in resin used to manufacture the Meal Bag. The retort and non-retort pouches are not significant because they cannot be recycled. The MRE in the new nanocomposite packaging survived the airdrop even though packaging had some defects. The air drop and transportation studies were also successful with inspection of defects comparable to the controls. The sensory panels conducted with consumer panels and technical panels were acceptable from the initial time to three years.

The processing and manufacturing of the pouches were conducted on conventional processing equipment at AmeriQual Packaging. The AmeriQual representatives determined that the nanocomposite packaging could be easily filled, sealed and assembled. Temperature controls needed to be adjusted to heat seal the Meal Bags. Once they optimized their dwell time settings for sealing the bags, all pouches were acceptable. NSRDEC worked closely with AmeriQual on the processing of the food and the assembly before, during and after the full effort. The non-retort film fit AmeriQual's equipment which fabricated the pouches in-line with the filling of the pretzels. The retort pouches were already produced for AmeriQual to fill them with penne pasta and commercially sterilize them by retort methods. The food passed all the sterility tests and quality control inspections after filling and assembling the containers into pallet loads. NSRDEC also observed the production line of filling the fiberboard containers with the assembled nanocomposite ration packaging. AmeriQual used a “shoot” system to sort all the Meal Bags that then got placed into the fiberboard containers. The nanocomposite packaging did not slide down the chute as well as the control packaging and on occasion the assembler had to feed them manually. Other than that, the assembly operation occurred smoothly without any problems or delays.

Overall, the nanocomposite packaging has been demonstrated to be comparable in performance to the current control packaging with a reduction in solid waste. The Meal Bags can easily be incorporated into the recycling waste stream, but the non-retort and retort nanocomposite structures cannot.

Since the military is moving toward Micro-wave Assisted Thermal Sterilization (MATS) methods, foil structures cannot be utilized with MATS. MATS is a direct heating method that offers faster thermal penetration, and better uniformity than conventional retorting or canning. Food is subject to high-temperature, short duration treatment allowing microwaves to penetrate the food, cooking packaged foods from the inside out, and preventing burning around the edges. MATS processing uses lower frequencies than those traditionally used to reheat foods and provide an effective method for sterilizing individually packaged heat sensitive foods. Preliminary studies have shown that these nanocomposite structures can successfully undergo MATS.

This project was presented to JSORF twice as informational briefings (2010 and 2012) and now work continues with the Combat Feeding Directorate (CFD) project “Barrier Coatings for Optimized Package Performance” that is performing accelerated storage studies at 100°C for other food items for retort and MATS sterilization. On completion of this project, a transition decision based on the results will be made at NSRDEC/CFD.

GLOSSARY OF DEFINITIONS

A-A-20195C –Packaging and Quality Assurance Provisions for CID A-A-20195C Snack Foods (Pretzels).

ACR-M-029 - CID for Meal, Ready-to-Eat (MRE), Assembly Requirements.

Air Drop Test - A test for transporting cases and/or pallet loads of MREs to see the effect on the packaging integrity.

Drop Test - A test for measuring the properties of a container by subjecting the packaged product to a free fall from predetermined heights onto a surface with prescribed characteristics.

Field Study - A study where the soldiers evaluate packaging performance and identify the packaging preference.

High Altitude Test - A test to determine the MRE bag and pouch integrity by exposing the packaging to high altitudes as a function of time.

Hypobarometric Test - A test also to determine the MRE bag and pouch integrity by exposing the package to high air permeability.

Insect Infestation -A test to determine if the military ration packaging can withstand high concentration exposure of insects.

Internal Pressure Test - A test to determine the behavior of the food pouches at a given pressure to prevent bursting.

Lipid Oxidation - The oxidation of lipids, especially in food or food products, leading to rancidity. This is an indication of rancidity.

Low Altitude Test - An air drop test that is performed at less than 2000 feet.

Microbial Analysis - A test on the retort pouch which quantifies the aerobic plate count of yeast and molds.

MIL-PRF-44073F - Performance Specification – Packaging of Food in Flexible Pouches.

Moisture Content - The quantity of water contained in a food material.

Oxygen scavenger's sachet - packets that are placed inside the pretzel non-retort food pouch used in this study to help extend product life and help improve product appearance. The sachet works by absorbing any oxygen left in the pack by oxidation of the iron powder contained in the sachet/label.

O**xygen Concentration -** amount of oxygen in the non-retort and retort pouch. For the retort pouch, there is the specification

PCR-P-036 - Penne with vegetables sausage crumb in spicy tomato sauce, packaged in a flexible pouch, shelf stable.

Polymer - Note polymer is a plastic and/or resin. These works can be used interchangeable in this demonstration plan.

Plastic recycling - This is the process of waste plastics and reprocessing the material into useful products, sometimes completely different in form from their original state.

Pull Out Date - Predetermined point in time at which the product is removed from storage evaluation.

Retort - A sterilization process of high temperature and pressure for the Meal, Ready-To-Eat.

Seal Strength - Force per unit width of seal required to separate progressively a flexible material under conditions of the test.

Shelf Life - Time a product may be stored before reaching endpoint.

Shelf Life Testing - Method to determine the effects of storage conditions on products' characteristics for purposes of determining a products shelf life.

Sensory Test - A panel which evaluates the flavor, odor, texture of the food product.

Storage Test – A test where food pouches are stored at certain temperature and/or humidity and then pulled out to be evaluated for a sensory test.

Transportation/Distribution Test - A test to see how the MRE packaging can withstand different altitudes, vibration, transportation and distributions cycles.

Vibration Test - A test used to assess the performance of a container with its interior packaging in terms of its ruggedness and the protection that it provides the contents when subjected to random vibration inputs**.**

Water Activity - Vapor pressure of water above a sample divided by that of pure water at the same temperature.

Zero Time Point -Time when shelf life testing begins.

1.0 INTRODUCTION

1.1 BACKGROUND

The environmental problem of solid waste generated by the Army is being addressed in this demonstration/validation program. The amount of packaging waste generated per Meal Ready-to-Eat (MRE) meal is 0.36 lb (22.9 % of total weight of ration). Based on the 2005 procurement of 40 million MREs, approximately 7200 tons of MRE packaging waste is generated every year. Deployed forces and contingency operations generate tons of solid waste that must be burned or backhauled to disposal sites at great expense. This coupled with the rising costs of packaging materials and disposal has dramatically increased the need to investigate alternative materials for combat ration packaging applications.

1.2 OBJECTIVE OF THE DEMONSTRATION

The objective of this effort is to demonstrate and validate new nanocomposite packaging for the military which has been achieved via earlier Environmental Quality Basic Research (EQBR) and Strategic Environmental Research and Development Program (SERDP) projects, as well as industry based developments in the area of nanocomposite packaging films that have matured into commercially available products. Nanocomposite packaging for the Meal Bag, non-retort and retort pouches was demonstrated and validated to reduce Department of Defense (DoD) specific waste problems by the development of lighter-weight and recyclable military ration packaging which also meet combat ration operational requirements. The goal was to transition mature technology to material converters and demonstrate manufacturability and durability of nanocomposite packaging structures within the military logistics system.

1.3 REGULATORY DRIVERS

This technology demonstration addresses Draft FY07 Army Environmental Requirements and Technology Assessment Document dated February 2007 and specifically addresses Requirement PP-5-06-01 “Zero Footprint Base Camps” which include elements of the previous Requirement, 3.5.c, “Solid Waste Reduction”, a top-ranked pollution prevention requirement. This program supported the following TRADOC Pamphlet 525-66, Military Operations, Force Operating Capabilities (FOCs): FOC-09-01 Sustainability, by achieving reductions in logistics demand and footprint; FOC-09-03 Power and Energy, by investigating technologies that show promise in replacing fossil fuels for packaging applications; and FOC 11-01 Human Engineering, by reducing Soldier dismounted movement approach load to 40 pounds and dismounted Soldier's fighting load to 15 pounds. This proposal also supports the Army Strategy for the Environment and Joint Vision 2020 doctrine by helping to bridge the gap between current and future joint capabilities; and by identifying new ways of exploiting emerging technological advances. It also contributed to simplifying deployment procedures, reducing weight of supplies, and minimizing environmental footprints.

Nanocomposite materials such as organically modified layered silicates are a new way to optimize and to improve polymer properties for high barrier packaging for the military rations. Polymers have been filled with compatible nanoparticles to improve mechanical properties such as tensile strength and toughness, slow diffusion to gases and moisture and impart dimensional stability at high temperature operations. Each nanoparticle is approximately 1 nm (10^{-9}m) in thickness and 100-500 nm in length. Owing to their ultra fine feature size and very high surface area (750 m^2/g), these filler particles convey improvements in properties without adversely affecting the processability of the polymer (i.e. viscosity), as is characteristic with conventional macroscopic fillers. When dispersed throughout the polymer and oriented properly, the nanoparticles align to form a physical barrier that slowed down the diffusion of gases through the polymer by formation of a tortuous diffusion path. This leads to significant improvement in oxygen and water vapor barrier properties which is essential for the extended shelf life of military rations. Nanocomposite Meal Bags, non-retort pouches and retort pouches were produced commercially, packaged with MRE food, and assembled into pallets of MRE cases. This packaging underwent a variety of testing to demonstrate and validate it for future military use. These tests included: sensory, storage study, rough handling, distribution/transportation, and insect infestation. This section is intended to provide an overview of the technology to be demonstrated.

2.0 DEMONSTRATION TECHNOLOGY

2.1 TECHNOLOGY DESCRIPTION

The objective of this effort is to demonstrate and validate new technology which has been achieved via earlier Environmental Quality Basic Research (EQBR) and Strategic Environmental Research and Development Program (SERDP) projects[1], as well as industry based developments in the area of nanocomposite packaging films that have matured into commercially available products . These research efforts have resulted in the development of a new generation of high performance packaging materials called nanocomposites by incorporating nanoparticles into commodity resins and thin film coatings used in packaging applications. Nanocomposite packaging structures were demonstrated and evaluated to reduce DoD specific waste problems by the development of recyclable and lighter-weight packaging[2], which also meet combat ration operational requirements. The effort validated the use of high performance, non-foil polymer film nanocomposite structures for application in current and future military rations. The goal is to transition mature technology to material converters and demonstrate manufacturability and durability of nanocomposite packaging structures within the military logistics system.

These nanocomposites which are targeted for the MRE Meal Bag, non-retort and retort pouches have shown significant improvements in barrier properties, as well as mechanical properties such as tensile strength and Young's modulus. Past and current research and development efforts conducted by NSRDEC and industrial partners have resulted in the first demonstration of a nanocomposite Meal Bag, non-retort, and retort pouch prototypes for the MRE that outperforms the current packaging. The improved properties of nanocomposite packaging promotes the replacement of the existing MRE Meal Bag with packaging that is approximately half the thickness of the current polyethylene material, and a potential to reduce plastic waste by over 1400 tons a year.

Enhancements made to high barrier materials through the use of nanotechnology and multilayer co-extrusion, allow for the replacement of the existing foil tri-laminate non-retort pouch with a material that reduce packaging waste, while also providing a recyclable packaging component.

The improved properties achieved through nanocomposite coatings allow for the replacement of the foil quad-laminate retort pouch, and has the potential to reduce the packaging waste by up to 22%, while also providing a recyclable package and minimizing existing performance issues such as stress induced flex cracks and pin holes. This conducted large-scale manufacturing and operational testing and evaluation of MREs which utilized nanocomposite packaging technology.

For packaging applications, nanocomposites have been shown to yield large improvements in barrier properties, as well as in physical properties such as tensile strength, tensile modulus (values obtained from stress/strain curve), and heat distortion temperature.[1,2,3] A key factor in determining the ultimate improvement in properties is the compatibility of the polymer/nanoparticle and the dispersion of the layered silicate particles within the polymer matrix. The nanoparticle typically used is organically modified montmorillonite layered silicate (MLS), a mica-type silicate, which consists of sheets arranged in a layered structure.

MLS is used due to its high cation exchange capacity and its high surface area, approximately 750 m^2/g and large aspect ratio (larger than 50) with a platelet thickness of 10Å (angstroms).[4] As shown in Figure 1, a conventional composite consists of two distinct phases, the polymer and the nanoplatelet, with minimal interface between them. Intercalation occurs when a small amount of polymer moves into the gallery spacing between the MLS platelets, causing less than 20-30Å separation between the platelets. This results in a well-ordered multilayer, with alternating polymer/clay layers. Exfoliation occurs when the clay platelets become further separated by the polymer chains. The separation distance can be from 80-100Å, which results in a well-dispersed nanocomposite with the potential of enhancing the mechanical, thermal and barrier properties.

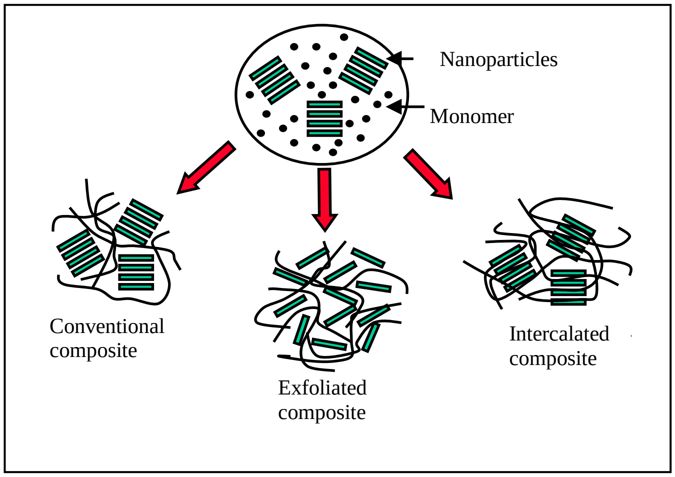

Figure 1. Nanocomposite Morphology

The dramatic reduction in permeability has been attributed in part to the presence of well-dispersed, large aspect ratio silicate layers, which cause solutes to follow a tortuous path. As shown in Figure 2, these results are in much larger effective diffusion distances, thereby lowering permeability. It has also been suggested that the presence of nanoparticles, with a very high surface area to volume ratio, significantly modifies the dynamic behavior of the polymer chains, leading to the observed property changes. [1]

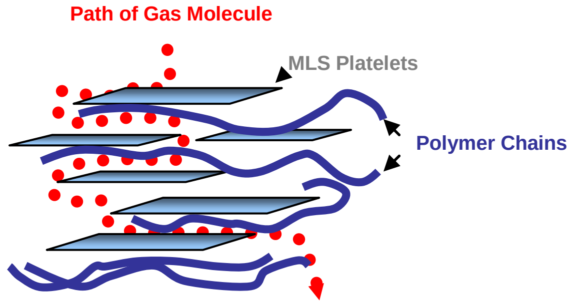

Figure 2. Tortuous Path Model

The interface between nanoparticles and polymer matrix reduces chain mobility, creating a reinforcement effect. This type of interface facilitates stress transfer to the reinforcement phase, thereby improving mechanical properties. A major advantage of nanocomposites, as compared to conventional fillers is that only 2-8% loading is required to achieve these property improvements.[5] These decreased loading levels and the intercalated/exfoliated morphology of the nanoparticles result in no increase in film thickness and no detriment to processability. A key factor in determining the ultimate improvement in properties is the compatibility of the polymer/nanoparticle and the dispersion of the nanoparticles within the polymer matrix, which NSRDEC has been successful in achieving. **Error! Bookmark not defined.**

Innovative research with NSRDEC and their collaborators has led to optimized nanocomposite formulations for the MRE Meal Bag, non-retort and retort pouches. Figure 3 illustrates the current structure of the Meal Bag and the pouches.

Figure 3. Current packaging structure of the MRE.

Table 1 represents the time line and different programs that funded this research and development. The nanocomposite Meal Bag initiated in a 6.1 basic research program and has successfully transitioned to the current ESTCP demonstration program.

Table 1. Nanocomposite Meal Bag Development

DATE	PROGRAM
2001-2003	Environmental Quality Basic Research Program (6.1)
2003-2005	SERDP, SI-1270, The Reduction of Solid Waste Associated with Ration Packaging (6.2)
2005-2008	U.S. Army Solid Waste Reduction Program (6.3)
2008-2011	ESTCP, SI-0186, Nanotechnology for Solid Waste Reduction of Military Packaging (6.4)

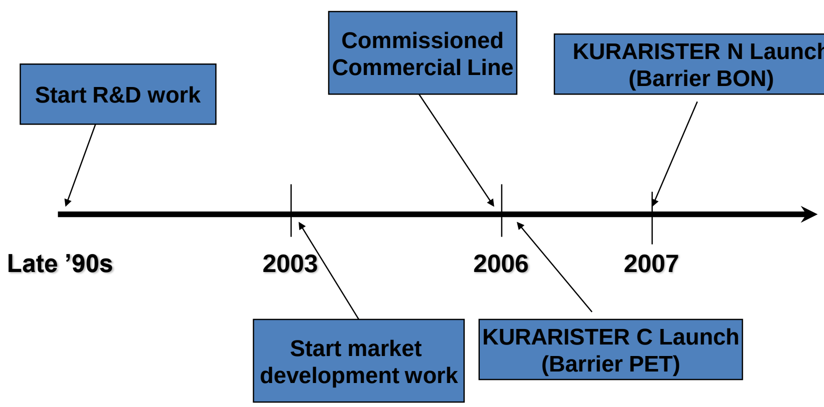

Figure 4. KURARISTER™ Development Time Line

The KURARISTER technology began in the late 1990's as shown in Figure 4 and today is being commercially produced with Food and Drug Administration approval for food contact. Expected applications in DoD is for food packaging for the military rations, but also this technology can apply to consumer food packaging applications. In addition, other DoD potential applications could include the bag that holds the Joint Service Lightweight Integrated Suit Technology (JSLIST). This is the current fielded ground crew chemical protective garment and the JSLIST suit bag made of a multi layer nylon/foil film. Another potential Army application is for tent and portable shelter applications.

2.2 TECHNOLOGY DEVELOPMENT

2.2.1 Meal Bag

The Meal Bag was fabricated from 11 mil at the outset of this project and is currently fabricated from 7 mil thick low density polyethylene (LDPE). NSRDEC engineers have successfully produced a 6 mil nanocomposite Meal Bag which meets all performance requirements. The nanocomposite Meal Bag formulation consists of melt processed LDPE and 7.5% (wt/wt) MLS nanoparticles, which show significant improvements in mechanical, thermal and barrier performance, compared to neat LDPE films, as evidenced in Table 2. These performance improvements were first demonstrated using laboratory scale, 5-pound processing trials. Subsequently, these trials were successfully scaled up to 300-pound and 1000-pound pilot plant trials. Successful scale-up is an essential milestone in proving the validity of the research, verifying the producibility of polymer nanocomposites, and transitioning the technology to advanced development.

Table 2. Summary of Nanocomposite Meal Bag Properties

	Current MRE Meal Bag	Neat Low-Density Polyethylene Film	Nanocomposite Low-Density Polyethylene Film
Film Thickness	11-mil	6-mil	6-mil
Oxygen Transmission Rate (cc-mil/m²-day)	8264	9097	3703
Young's Modulus (MPa)	127	93	186
Onset of Thermal Degradation (°C)	351	370	450
Insect Infestation Test	Pass	Fail	Pass

2.2.2 Non-Retort Pouch

The current non-retort pouch shown in Figure 3 is a tri-laminate structure with foil as the barrier layer. Kuraray and NSRDEC have successfully optimized multilayer film structures for the non-retort pouch, which utilize a nanocomposite coating as the barrier layer. Kuraray has developed a multilayer film with high barrier properties, suitable for applications where barrier to oxygen and water vapor are critical. Kuraray's nanocomposite barrier films incorporate functionalized nanoparticles into a coating for barrier polymers, nylon and/or polyethylene terephthalate (PET). These optimized formulations have produced films with >30% improvement in barrier properties against oxygen and water vapor in comparison to some earlier formulations. Kuraray has conducted research and worked with the team at NSRDEC to evaluate the feasibility of using

Kuraray's multilayer films for food packaging in an effort to reduce packaging waste for military applications. NSRDEC is satisfied with the performance properties and the focus was to manufacture sufficient quantities of film for further evaluation under this ESTCP program.

Kuraray America has completed the preparations for the lamination and pouch-making trials and has specified and acquired the necessary materials to produce the non-retort film– KURARISTER C, Toppan GL-ARH CPP, HDPE. The multi-ply adhesive laminated barrier non-retort structures were designed to minimize the oxygen transmission rate (OTR) and water vapor transmission rate (WVTR) for optimal performance. The non-retort structures were designed with KURARISTER C^{TM} barrier coated films, produced by Kuraray. KURARISTER films utilize a thin hybrid barrier coating (< 1 mm) that is applied to both sides of either an oriented polyester film substrate. KURARISTER™ films have demonstrated low and consistent oxygen barrier properties. KURARISTER™ has also been thoroughly evaluated for abuse resistance and the results indicate that the affects of flexing, folding, and scratching do not significantly deteriorate the barrier properties. Kuraray researched and chose Rohm & Haas MorFree 225/C33 as the optimal adhesive for the film laminations. Kuraray America utilized the services of Packall Packaging in Brampton, Ontario Canada, which has experience laminating solvent less urethane adhesives similar to the MF225/C33, to laminate the films and then AmeriQual has converted the films to pouches. The roll width is 16.625 inches with a 6 inch core.

2.2.3. Retort Pouch

The current retort quad-laminate pouch structure is also shown in Figure 3. Kuraray has developed a polymer film structure, which employs a high barrier nanocomposite coating, for retort pouch applications. This barrier material, KURAISTER N™ is thin (1um), but extremely durable coating on both sides of a nylon substrate. Toppan GL-ARH, an inorganic barrier coated film, was also used to enhance water vapor barrier. Rohm and Haas's MorFree 225/C33 was chosen as the optimal adhesive for the film laminations to avoid a potential blistering issue in double barrier lamination (Toppan GL-ARH // KURARISTER N) This material has been shown to yield excellent barrier properties before and after retort. It also has undergone Gelbo flex testing experiments and the OTR is nearly the same after the flexing suggesting that the nanocomposite coating is extremely durable. Kuraray also utilized the services of Packall Packaging in Brampton, Ontario Canada, to laminate the films and form the pouches.

It is essential to demonstrate and validate this technology through the large-scale manufacturing and operational testing of MREs which utilize nanocomposite packaging. These engineering accomplishments led to lightening the load for the Soldier and decreasing the amount of solid waste generated by the Army. For all of these packaging components, it is essential to demonstrate that these films can be manufactured into pouches and pass all the success criteria. This included three different nanocomposite structures in the MRE ration as depicted in Figure 5.

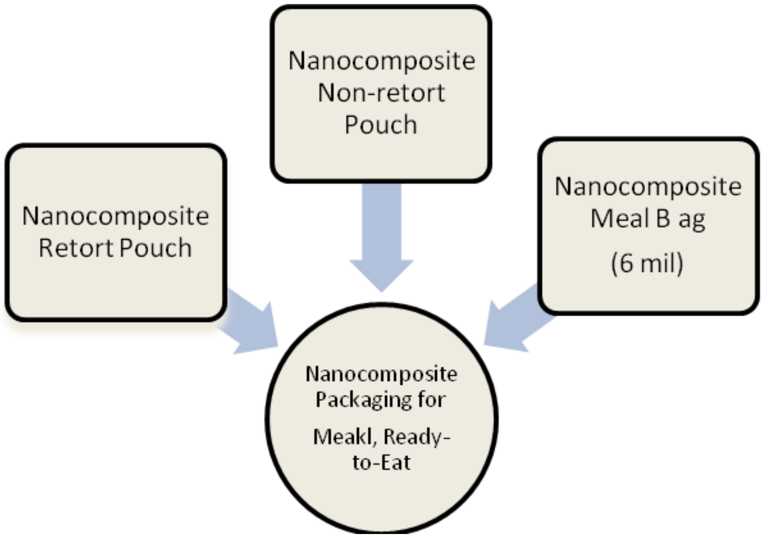

Figure 5. Three Nanocomposite Structures for the MRE.

The pouch materials are identified in Table 3 for both the non-retort and retort pouches. Specifically, the structures are shown in Table 4 for the non-retort pouch and Table 5 for the retort pouch. Table 6 shows the dimensions for the non-retort roll stock and the retort pouches.

Table 3. MRE Non-Retort and Retort Pouch Materials

MF225	Rohm and Haas Mor Free 225 +C33 solventless retort grade adhesive
HDPE	Pliant 4 mil blown HDPE sealant film
CPP	Pliant 4 mil cast PP sealant film
EF-XL_{15}	EVAL 15 micron bi-axially oriented 32 mol% EVOH film
K-C	KURARISTER^{TM} C
K-N	KURARISTER^{TM} N
GL	Toppan GL-ARH (inorganic barrier coated PET)

Table 4. MRE Non-Retort Pouch Structure

HDPE
MF225
EF-XL_{15}
MF225
K-C

Table 5. MRE Retort Pouch Structure

CPP
MF225
K-N
MF225
GL

Table 6. MRE Pouch Film Size and Pouch Size

	Retort Pouch	Non-Retort Roll Stock
Outer Dimension	12.06 x 20.64 cm (4.75 x 8.13 in)	—
Seal Width	0.95 cm (0.38 in)	—
Tear Notch	3.81 cm (1.5 in) from pouch bottom	—
Roll Width	—	42.43 cm (16.63 in)
Core	—	15.24 cm (6 in)

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

The overall advantage of this nanotechnology packaging was that the amount of solid waste for the military was significantly reduced. All polymeric, possibly recyclable Meal Bags and food pouches, are being produced that eliminate plastic ration packaging from the waste stream. The food pouches of the existing technology are not recyclable due to the foil layer for barrier. The nanocomposite packaging is being produced as multilayered polymeric structures with recyclable polymers and compatible nanoparticles in low percentages.

Calculations, shown below, were carried out to determine the magnitude of waste savings. This is relative to the demonstration as this would be meeting the overall objective of the ESTCP project. The data required is the weight of the Meal Bag after commercially producing it. The criteria to determine the success is a decrease in weight by 20%. Some calculations have been done initially based on a 100 million MRE procurement in Table 7.

Table 7 Meal Bag Weight Difference

Sample	Weight (lb)
LDPE meal bag	0.0750
Nanocomposite meal bag	0.0397
MRE inside of LDPE meal bag	1.7556
MRE inside of nanocomposite meal bag	1.7196
Differences in weight of MRE meal bags	0.035
Difference in weight for 100M MRE rations	3,500,000

In addition, the U.S. Army in collaboration with industry has developed waste to energy converters that are being demonstrated for military use. The nanocomposite polymeric packaging waste would be able to be used in the waste to energy converters.

For the Meal Bag, the advantage of the new structure is that it is thinner than the existing Meal Bag, so less polymer resin is needed to make the Meal Bag. This Meal Bag has better water vapor and oxygen barrier performance as well as improved mechanical and thermal properties. The advantages of the current Meal Bag are that it has been used for over 20 years and has performed well for the U.S. Army, however it may be over-engineered. The new technology may allow some commercial items in the MRE to not require overwrapping with a food pouch since it contains some barrier enhancement.

Other advantages of the new technology for the non-retort and retort pouches are the following: simplified processing, less processing steps, less production costs and an all polymeric structure. No limitations are identified. The processing methods are the same as the current pouches, but in this case the foil lamination step would be eliminated, therefore potentially decreasing the costs. One advantage of the current technology for the non-retort and retort pouches is that the barrier is maintained without the foil, therefore eliminating pin holes and stress cracking that occurs with current foil based packaging. Another significant advantage to the new technology is that the nanocomposite food pouches could be microwaved or could withstand novel sterilization processes such as high pressure sterilization and MATS, methods which are currently being investigated as future sterilization methods for U.S. Army.

The major cost consideration involved with current practices and technologies is that the food pouches (both non-retort and retort) are produced with many processing steps which requires lamination of a aluminum metal to a plastic film. Although the KURARISTER technology involves lamination, there are some advantages to this polymeric lamination process. MRE pouches using KURARISTER were produced on a single pass solvent less laminator. For example, the lamination of CPP to K-N is the first step, and then the film cures for 10 days so the adhesive sets before further processing. The final step is laminating the CPP//K-N to the GL.

Foil is a very delicate material with more of a tendency to tear during lamination than a polymer film, so production output could be higher. Also, yield losses at start-up can be higher with foil laminations due to damage on the edges and surface of the foil roll. Pinholes are more prevalent in foil than polymeric laminations after typical abuse. The labor costs and machine costs are potentially less with the new technology.

3.0 PERFORMANCE OBJECTIVES

Table 8, Table 9, and Table 10, contain the performance objectives for the Meal Bag, non-retort pouch, retort pouch and the overall MRE performance.

3.1 Meal Bag Performance Objectives

Table 8. Performance Objectives - Meal Bag

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives				
Assure recyclability of Meal Bag	Melt temperature of polymer (ºC)	Obtain melt points for reprocessing the Meal Bag	Meal Bag polymer melts at 115°C ± 10°F	**MET**
Maintain resistance to insect infestation	Percentage of insect penetrations per 30 MREs™	Inspection of the Meal Bag after insect exposure	<20% penetration failure	**MET**
Maintain Meal Bag integrity with ease of opening (top seal)	Percentage of meal bags that meets military specification for seal strength (lb/in) for 18 Meal Bags	Seal strength testing	>90% of the average seal strengths are >4 lb/in but <10lb/in	**MET**
Maintain integrity of Meal Bag (bottom seal)	Percentage of meal bags that meets military specification for seal strength (lb/in) for 18 Meal Bags	Seal strength testing	>90% of closure seal will have average seal strengths of >4 lb/in	**MET**
Assure integrity of Meal Bag after environmental rough handling	Percentage of defects	Inspection of the Meal Bag after rough handling	<15% failure rate	**MET**
Reduce disposal waste	Weight of waste in lbs	Weight of individual Meal Bags	Each Bag is <0.075 lb	**MET**
Reduce plastic(resin) amount during manufacturing	Weight in lbs	Amount of plastic for Meal Bag trial	Amount of plastic per Bag is <0.075 lb	**MET**
Qualitative Performance Objectives				
Assure recyclability with industry	Ability of industry to recycle	Response and trials from the recycling companies	Industry accepts Meal Bag (flake) for recycling	**MET**

3.1.1 Assure Recyclability of Meal Bag

This objective determined the recyclability of the Meal Bag. Plastic recycling is a process where the Meal Bags, which would otherwise become solid waste, are collected, melt processed, and returned to use in another plastic product. This is relevant to this demonstration/validation project as this could lead to the reuse of Meal Bags, and also eliminate Meal Bags from the military waste stream. The metric is the melt temperature of the LDPE plastic, which is used in the manufacturing of the Meal Bag. Most plastics exhibit a unique temperature at which melting occurs. The data requirement would be verification of the melt temperature after the Meal Bag has been produced and used in the field, as this would indicate that the Meal Bag can be reprocessed. The melt temperatures are determined by differential scanning calorimetry (ASTM D3418) and then the material can be remelted in the laboratory scale extruders at the NSRDEC. The success criterion is if the Meal Bag's measured melt temperature is in the range of 115 ± 10°C. Further testing with industrial recyclers were performed.

3.1.2 Maintain Resistance to Insect Infestation

This objective was to confirm insect resistance of the Meal Bag, which prevents insects from boring through the package and contaminating the food. This is relevant to the demonstration plan for validating packaging performance. If insects bore through the Meal Bag, this may allow them to penetrate the food pouches creating a food safety issue for the soldiers. The metric is percentage of insect penetrations per 30 MREs. The data required for this objective are the results from an insect infestation experiment with the nanocomposite Meal Bags. Results from this study indicated where, when and what types of insects may penetrate the Meal Bag. A complete inspection of the Meal Bags and documentation of the penetration locations at certain time periods were performed. A criterion for success is that there is less than 20% penetration failure range in the insect testing in comparison to the current component MREs.

3.1.3 Maintain Meal Bag Integrity with Ease of Opening (Top Seal)

This objective was to assure that the Meal Bag manufacturer seal performs in accordance with the specification ACR-M-029, (MRE Assembly Requirements) with ease of opening for the soldier. The metric is percentage of Meal Bags that meet military specification for seal strength (lb/in) for 18 Meal Bags. Seal strength is a quantitative measure for use in process validation, control and capability. Seal strength testing is the data requirement. Seal strength is relevant to opening force (lb/inch) and package integrity. The seal strength of the peelable (top) seal cannot be less than 4 lb/in, yet not greater than 10 lb/in to facilitate opening of the Meal Bag. The success criterion is that greater than 90% of the average seal strengths are greater than 4 lb/in but less than 10 lb/in.

3.1.4 Maintain Integrity of Meal Bag (Bottom Seal)

This objective was to assure that the Meal Bag closure seal performs in accordance with the specification ACR-M-029. The metric is percentage of Meal Bags that meet military specification for seal strength (lb/in) for 18 Meal Bags. Seal strength is a quantitative measure for use in process validation, control and capability. Seal strength testing is the data requirement. Seal strength is relevant to opening force (lb/inch) and package integrity. The closure (bottom) seal of the Meal Bag must have average seal strength of not less than 4 lb/in with no individual Meal Bag test result less than 3 lb/in. The success criterion is that more than 90% of the average seal strengths are greater than 4 lb/in.

3.1.5 Assure Integrity of Meal Bag after Environmental Rough Handling

This objective was to determine that the MRE Meal Bag withstands rough handling at different environmental conditions. This is important for the demonstration as the MREs can experience abusive handling before arriving at their final destination where they are consumed by Warfighters. If the packaging has any defects then the food safety could be in jeopardy. The metric was the percentage of defects. MREs were tested using the following methods, D999-07 (Methods for vibration of shipping containers), and D-5276-98 (Test Method for drop test of loaded containers) where the samples were conditioned at low, standard and high temperature conditions according to MIL-PRF-44073F. Inspection of the Meal Bags after the testing was recorded and failure rates were determined. The success rate would be less than 15% failure.

3.1.6 Reduce Disposal Waste

This objective was to reduce the amount of solid disposal waste for the military with the nanocomposite Meal Bag. Reducing the overall waste in the field, due to Meal Bag weight reduction, is one of the most important performance objectives. The nanocomposite Meal Bags are thinner and weigh less than the existing bag. The metric is the weight of waste resulting from Meal Bag disposal in pounds. The data requirement is determining the weight of the individual nanocomposite Meal Bag. A cumulative waste value was calculated by summing the individual weights of the Meal Bag waste. The success criteria is that each bag weighs less than 0.075 lb. which is the weight of the existing Meal Bag

3.1.7 Reduce Polymer (Resin) Amount During Manufacturing

This objective addressed the reduction of polymer used during manufacturing of the Meal Bags through the production of a thinner Meal Bag. The metric was the weight in pounds of plastic resin used for the production trial of a predetermined quantity of Meal Bags. The data required would be the amount of plastic for the production trial. The success criterion is that the amount of plastic per Meal Bag would be less than 0.075 lbs.

3.1.8 Assure Recyclability with Industry

This objective assured that industry can recycle the Meal Bag. Although melt temperature and reprocessability is addressed in section 3.11, industry must test the material formulation on their specific processing machinery and assess compatibility with other polymers. The metric is the ability for industry to recycle. The data requirement is a trial and feedback from the recycling companies. The success criterion is if the industry accepts the Meal Bag for recycling.

3.2 Non-Retort Pouch Performance Objectives

Table 9. Performance Objective - Non-Retort Pouch

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives				
Assure recyclability of pouch	Melt temperature of polymer (°C)	Obtain melt points and reprocess the pouch	Pouch has melt temperature of 200°C ± 20°C	**NOT MET**
Maintain low oxygen concentration	Oxygen concentration %	Oxygen concentration as percentage within pouch	>90% of pouches with <0.3% oxygen	**MET**
Maintain resistance to insect infestation	Percentage of penetrations per 30 MREs	Inspection of the pouch after insect exposure	<20% penetration failure	**MET**
Assure food is not rancid	Hexanal quantity generated in sample (ppm)	Head space analysis for hexanal quantity	<5 ppm of hexanal in all pouches	**MET**
Maintain integrity of pouch	Percentage of pouches that meet military specification for burst strength	Internal pressure testing	>90% of the pouches exhibit no rupture or seal separation > 1/16 of an inch	**MET**
Assure integrity of pouch after environmental rough handling	Percentage of defects (leaks in the pouches)	Inspection of the pouch after rough handling	<15% failure rate	**MET**
Maintain shelf life	Quantity of water contained in a sample expressed as a percentage where 0% is completely dry	Moisture weight loss of food product	Water content between 3-5%	**MET**
Maintain shelf life	Ratio of vapor pressure of water above a sample divided by pure distilled water	Water activity analysis of food product	Water activity is between 0.10-0.50	**MET**
Qualitative Performance Objectives				
Assure recyclability with industry	Ability of recycling in industrial stream	Response and trials from the recycling companies	Industry accepts pouch (flake) to be recycled	**NOT MET**

3.2.1 Assure Recyclability of Pouch

This objective determined the recyclability of the non-retort pouch. Plastic recycling is a process where the non-retort pouches, which would otherwise become solid waste, are collected, melt processed, and returned to use in another plastic product. This is relevant to this demonstration/validation project as this could lead to the reuse of the non-retort pouch and also eliminate it as part of the military waste stream. The metric is the melt temperature of the plastic which is used to make the non-retort pouch (a multilayer structure). Most plastics exhibit unique melting temperatures. Verification of the melt temperature after the non-retort pouch has been produced and used in the field would be an indicator that the non-retort pouch can be reprocessed. The melt temperatures can be determined by differential scanning calorimetry (ASTM D3418) and then the material remelted in the laboratory scale extruders at the NSRDEC. The success criterion is if the non-retort pouch has the melt temperature range of 200 ± 20°C.

3.2.2 Maintain Low Oxygen Concentration

This objective assured that the package maintains an acceptable oxygen concentration to avoid food spoilage. Oxygen is a reactive compound that plays a key role in food spoilage and food quality. Most reactions for rancidity, molds and flavor are dependent on oxygen concentration. This is relevant to the demonstration since food safety and quality need to be maintained and monitored for the soldier throughout this study. The metric is percent concentration of oxygen, and the data requirement is oxygen concentration within the non-retort pouch. This is measured with the OxySense® 4000B Oxygen Analysis System or with the MOCON system, which are both explained in detail in Appendix A4. The success requirement is that greater than 90% of the pouches must have less than 0.3% oxygen as specified in U.S. Army's Performance Requirements A-A-20195C.

3.2.3 Maintain Resistance to Insect Infestation

This objective confirmed that there are no insects boring through the non-retort pouch to contaminate the food. This is relevant to the demonstration plan for validating packaging performance. If insects bore through the non-retort pouch, then the food is not safe for the soldiers to consume. The metric is percentage of insect penetrations per 30 MREs. The data requirements are results from insect infestation experiments with the nanocomposite non-retort pouch. Results from this study were used to determine where, when and what types of insects may penetrate the non-retort pouch. Complete inspection of the non-retort pouch and documentation of the penetration location at certain time periods were performed. Criteria for success are that there is less than 20% penetration failure in comparison to the current MRE non-retort pouch.

3.2.4 Assure Food is Not Rancid

This objective assured that the food quality is maintained after storage. This is crucial for the demonstration to validate that the nanocomposite packaging keeps the food from degrading, and maintains food quality for the soldier. The metric is hexanal quantity in parts per million that is generated by the food while packed in the non-retort pouch. The data requirement is data from head space gas chromatography/mass spectrometry. Data was collected after storing the pouches at different conditions as a function of time. The success criteria is that there is less than 5 parts per million of hexanal in each individual non-retort pouch.

3.2.5 Maintain Integrity of Pouch

This objective was assuring that the non-retort pouch performs in accordance with the specification ACR-M-029 (MRE Assembly Requirements) and MIL-PRF-44073 (Packaging of Food in Flexible Pouches). The metric is percentage of non-retort pouches that do not rupture or burst. The data requirement is internal pressure testing using a Lippke 2500 SL. The success criterion is that greater than 90% of the non-retort pouches exhibit no rupture or seal separation greater than 1/16 of an inch.

3.2.6 Assure Integrity of Non-Retort Pouch After Environmental Rough Handling

This objective was to determine that the MREs non-retort pouch withstands rough handling at different environmental conditions. This is important for the demonstration as the MREs can encounter abusive handling before arriving at their final destination where Warfighters consume the MREs. If the packaging has any defects then the food safety could be in jeopardy. The metric was the percentage of defects. MREs were tested using the following methods, D999-07 (Methods for vibration of shipping containers), and D-5276-98 (Test Method for drop test of loaded containers) where the samples were conditioned at low, standard and high temperature conditions and inspected according to MIL-PRF-44073F Inspection of the pouches after the testing for leaks were recorded and failure rates were determined. The success rate would be less than 15% failure.

3.2.7 Maintain Shelf Life (Water Content)

This objective was to maintain the shelf life of the product by tracking the water content of the food samples. Water content influences the texture, taste and appearance of food products. Water content analysis allows for a quantitative measure of the total amount of water present in a food item; however water content alone is not a reliable indicator for predicting microbial responses and chemical reactions in materials. Water content measurements are important to assure that no water is entering the pouches during storage. The metric is the quantity of water contained in the food samples expressed as a percentage, where 0% is a dry sample. Moisture weight loss of food products is determined by drying the food in a vacuum oven and then reweighing. Water content of 3-5% is the success criteria.

3.2.8 Maintain Shelf Life (Water Activity)

This objective is to also maintain shelf life, which is indicated by the water activity. Water activity influences color, odor, flavor, texture, and shelf-life of many products. It predicts safety and stability with respect to microbial growth, chemical and biochemical reaction rates, and physical properties. The nanocomposite non-retort pouches must be analyzed for water activity to confirm the pouches are minimizing water uptake. The metric is the ratio of vapor pressure of water above a sample divided by the vapor pressure of the pure distilled water sample. The water activity data requirements are performed with an Aqua lab apparatus which measures water activity based on energy status of the system, or how water is associated with other components of the food. Water activity is unitless value and the success criteria need to be between 0.30-0.50.

3.2.9 Assure Recyclability with Industry

This objective assured that industry can recycle the non-retort pouch. Although melt temperature and reprocessability is addressed in section 3.21, industry must test this material formulation on their specific processing machinery and assess compatibility with other polymers. Being a multilayer structure can create compatibility complications for some industrial recycling equipment. The metric is the ability for industry to recycle. The data requirement is a trial and feedback from the recycling companies. The success criterion was the industry accepted the non-retort pouch for recycling.

3.3 Retort Pouch Performance Objectives

Table 10. Performance Objectives - Retort Pouch

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives				
Assure recyclability of pouch	Melt temperatures of polymers (°C)	Obtain melt points and reprocess the pouch	Melting temperature is 200°C ± 20°C with reprocessability capability	**NOT MET**
Maintain low oxygen concentration for shelf life requirements	Concentration of oxygen (cc) for	Oxygen concentration within pouch	>90% at 20 cc or less	**MET**
Maintain resistance to insect infestation	Percentage of penetrations per 30 MREs™	Inspection of the pouch after insect exposure	<20% failure	**MET**
Assure shelf stability and microbial validation	Number of colonies per gram (cfu/gram)	Aerobic plate counts (yeast and mold colonies) present on food product	<10 cfu/gram	**MET**
Assure food is not rancid	Hexanal quantity generated in sample (ppm)	Headspace analysis	<5 ppm of hexanal	**MET**
Maintain integrity of pouch	Percentage of pouches that meets military specification for burst	Internal pressure testing	>90% of the pouches exhibit no rupture or seal separation > 1/16 of an inch	**MET**
Assure integrity of pouch after environmental rough handling	Percentage of defects (leaks in the pouches)	Inspection of the pouch after rough handling	<15% failure rate for defects	**MET**
Maintain shelf life	Quantity of water contained in a sample expressed as a percentage (where 0% is completely dry %)	Moisture weight loss tests on food product	Moisture content is 75 to 80%	**MET**
Maintain shelf life	Ratio of vapor pressure of water above a sample divided by pure distilled water	Water activity analysis on food product	Water activity is between 0.95-98	**MET**
Qualitative Performance Objectives				
Assure recyclability with industry	Ability of recycling in industry	Response and trials from the recycling companies	Industry accepts pouch to be recycled	**NOT MET**

3.3.1 Assure Recyclability of Pouch

This objective determined the recyclability of the retort pouch. Plastic recycling is a process where the retort pouch, which would otherwise become solid waste, is collected, melt processed, and returned to use in another plastic product. This is relevant to this demonstration/validation project as this could lead to the reuse of the retort pouch and also eliminate retort pouches from the military waste stream. The metric is the melt temperature of the plastic, which is used to make the nanocomposite retort pouch. Most plastics exhibit unique melting temperatures. Verification of the melt temperature after the retort pouch has been produced and used in the field would be an indicator that the retort pouch can be reprocessed, and therefore recyclable. The melt temperatures can be determined by differential scanning calorimetry (ASTM D3418) and then the material can be remelted in the laboratory scale extruders at the NSRDEC. The success criteria is if the retort pouch indeed has the melt temperature of 200 ± 20°C

3.3.2 Maintain Low Oxygen Concentration for Shelf Life Requirements

This objective assured that the package maintains a low oxygen concentration to avoid food spoilage. Oxygen is a reactive compound that plays a key role in food spoilage and food quality. Most reactions for rancidity, molds, and flavor changes require oxygen. This is relevant to the demonstration since the food safety needs to maintained and monitored throughout the study. The metric is concentration of oxygen, and the data requirement is oxygen concentration within the retort pouch. This is measured with the OxySense® 4000B Oxygen Analysis System or with the MOCON system which is explained in detail in the Appendix A4. The success requirement is that greater than 90% of the pouches must have less than .20 cc oxygen as specified in U.S. Army's Performance Requirements MIL-PRF-44073F.

3.3.3 Maintain Resistance to Insect Infestation

This objective confirmed that there are no insects boring through the retort pouch to contaminate the food. This is relevant to the demonstration plan for validating packaging performance. If insects bore through the nanocomposite retort pouch, then the food would be spoiled and unsafe for the soldiers to consume. The metric is percentage of insect penetrations per 30 MREs. The data requirements are results from insect infestation experiments with the nanocomposite retort pouches. Results from this study were used to determine where, when and what types of insects may penetrate the retort pouch. Complete inspection of the retort pouch and documentation of the penetration location at certain time periods were performed. A criterion for success is that there is less than 20% penetration failure in comparison to the current MRE retort pouch.

3.3.4 Assure Shelf Stability

This objective assured that the food pouches are able to withstand shelf stability and microbial validation. The MREs must maintain high quality and be acceptable to the Warfighter for a minimum of three years storage at 80ºF and six months at 100ºF. This objective relates to the food safety and shelf life of the food. The pouches were stored at various temperatures for different periods of time. Microbiological tests were conducted throughout the storage study, at predetermined intervals, to determine the number of colonies of microorganism per gram, which is the metric for this objective. The data requirement is a test analyzing the aerobic plate count for yeast and mold colonies present in the retort pouch food product. The success criterion is if there are less than 10 colonies per gram in the food sample.

3.3.5 Assure Food is Not Rancid

This objective assured that the food quality is maintained after storage. This is crucial for the demonstration to validate that the nanocomposite packaging keeps the food from degrading, and maintains food quality for the soldier. The metric is hexanal quantity in parts per million that is generated by the food while packaged in the retort pouch. The data requirement is data from head space analysis using gas chromatography/mass spectrometry. Data was collected after storing the pouches at different conditions as a function of time. The success criteria is that there is less than 5 parts per million of hexanal in each individual retort pouch.

3.3.6 Maintain Integrity of Pouch

This objective was assuring that the non-retort pouch performs in accordance with the specification ACR-M-029 and MIL-PRF-44073. The metric is percentage of retort pouches that do not rupture or burst. The data requirement is internal pressure testing using a Lippke 2500 SL. The success criteria is that greater than 90% of the non-retort pouches exhibit no rupture or seal separation greater than 1/16 of an inch.

3.3.7 Assure Integrity of Retort Pouch After Environmental Rough Handling

This objective is that the MREs retort pouch withstands rough handling at different environmental conditions. This is important for the demonstration as the MREs can encounter abusive handling before arriving at their final destination where Warfighters consume the MREs. If the packaging has any defects then the food safety could be in jeopardy. The metric was the percentage of defects. MREs were tested using the following methods, D999-07 (Methods for vibration of shipping containers), and D-5276-98 (Test Method for drop test of loaded containers) where the samples are conditioned at low, standard and high temperature conditions according to MIL-PRF-44073F. Inspection of the pouches after the testing for leaks was recorded and failure rates were determined. The success rate would be less than 15% failure.

3.3.8 Maintain Shelf Life (Water Content)

This objective is to maintain the shelf life of the product by tracking the water content of the food samples. Water content influences the texture, taste and appearance of food products. Water content analysis allows for a quantitative measure of the total amount of water present in a food item; however water content alone is not a reliable indicator for predicting microbial responses and chemical reactions in materials. Water content measurements are important to assure that no water is entering or exiting the pouches during storage and use. The metric is the quantity of water contained in the food samples expressed as a percentage where 0% is a dry sample. Moisture weight loss of food products is determined by drying the food in a vacuum oven. Water content of 8.5-12% is the success criteria.

3.3.9 Maintain Shelf Life (Water Activity)

This objective is to also maintain shelf life, which is indicated by the water activity. Water activity influences color, odor, flavor, texture, and shelf-life of many products. It predicts safety and stability with respect to microbial growth, chemical and biochemical reaction rates, and physical properties. The nanocomposite retort pouches must be analyzed for water activity to confirm the pouches are minimizing water uptake or loss. The metric is the ratio of vapor pressure of water above a sample divided by pure distilled water. The water activity data requirements are performed with an Aqua lab apparatus which measures water activity based on energy status of the system, or how water is associated with other components of the food. Water activity is a unitless value and the success criterion needs to be between 0.5-0.7.

3.3.10 Assure Recyclability with Industry

This objective assures that industry can recycle the retort pouch. Although melt temperature and reprocessability is addressed in section 3.2.1, industry must test this material formulation on their specific processing machinery and assess compatibility with other polymers. The metric is the ability of industry to recycle. The pouch being a multilayer structure can create compatibility complications for some industrial recycling equipment. The date requirement is a trial and feedback from the recycling companies. The success criterion was if the industry accepted the retort pouch for recycling.

3.4 Overall MRE System Performance Objectives

Table 11. Performance Objectives - Overall MRE System Performance

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives				
Soldier acceptance of food and packaging	Scaled scores from questionnaire	Scores on survey from individual soldiers	Average score >5.0 on hedonic scale	**MET**
Reduce amount of solid waste requiring disposal	Tons/day of solid, non-hazardous ration related waste sent to landfill	Disposal data for solid waste	>30% overall weight reduction with 20% from tons/day disposed	**MET**
Assure MRE can withstand air drop transportation	Percentage of failures from packaging seals and bursts	Percentage of defects on dropped MREs	<12% failure rate	**MET**
Assure MRE can withstand distribution / transportation study	Percentage of packaging defects	Inspection of MREs after distribution and transport cycle	<20 % failure rate	**MET**
Acceptance of food from sensory panel	Number (whole integer) for rating the food	Panel evaluation for flavor, taste, odor and texture	>5.0 on hedonic scale >90% acceptance	**MET**
Qualitative Performance Objectives				
Ease of processing, filling and packing the nanocomposite ration packaging	Observations during the processing, packing and filling	Feedback and inspection from the converter on the filling and packing of the MREs™	Pass end item inspection at co-packers with certificate of conformance and production report	**MET**

3.4.1 Soldier Acceptance of Food and Packaging

This qualitative objective is to obtain approval of the packaging from the customer, the soldier. This is relevant to the demonstration since the soldier is the designated customer of the rations and ration packaging. The soldier was involved in a field study using the nanocomposite packaging and surveyed on this packaging and the food products. The metric is the scaled scores from questionnaires. The data requirements are that the surveys must be filled out by the soldier and the individual scores are reported. The success criterion is that the average score is greater than 5.0 of the hedonic scale.

3.4.2 Reduce Amount of Solid Waste Requiring Disposal

The objective is to reduce the amount of solid waste requiring disposal and this has substantial relevance to the demonstration for the overall goal to reduce solid waste.
Studies have shown that solid waste is generated at a rate of about 4 lbs per person per day for Force Provider camps and Army field exercises, most of which originates from foodservice operations. This is relevant to the demonstration as the overall goal of this environment

demonstration is to reduce the amount of solid waste for the military. Deployed forces and contingency operations generate tons of solid waste that must be burned or backhauled to disposal sites at great expense. The metric to assess is the tons/day of ration waste generated by the military. A characterization study generating the amount (weight) of the disposed solid waste is necessary. The success would be if there is a greater than 30% reduction in the solid waste with 10% being able to be recycled.

3.4.3 Assure MRE Can Withstand Air Drops

This objective determines if the packaging can withstand air drops. Airdrop survival for the MRE is crucial with deployed soldiers. The metric is the percentage of failures from packaging seals and bursts. The data requirement is to exam all MREs components after air drops and altitude chamber testing to determine the percentage of failures. The success criterion is determined to be less than 12% failure rate.

3.4.5 Assure MRE Can Withstand Distribution / Transportation Study

The objective was the survival of the MREs after transportation and distribution. The MREs were subjected to, extreme environmental conditions, and a rigorous transportation route which is relevant for this demonstration plan to assure survival in all types of distribution and transportation scenarios. An official inspector is needed to simply evaluate the packaging for defects after the MREs have undergone the various distribution and transportation scenarios. A 20% failure rate is acceptable for this objective.

3.4.6 Acceptance of Food From Sensory Panel

This objective was to determine the acceptability of the food from the sensory panel. This is important for the demonstration/validation study since this is a trained panel who evaluates the packaging with respect to ease of opening, performance and appearance, and food products with respect to flavor, taste, odor and texture. The metric is the number that is given as a rating on the surveys. The data requirement involves panel evaluation forms and questionnaires throughout the storage study. The success criterion is greater than 5.0 on the hedonic scale with 90% acceptance.

3.4.7 Ease of Processing, Filling and Packing the Nanocomposite Ration Packaging

The Qualitative Performance Objectives were the ease of processing and packaging. This is important as the pouches and bags need to be made on the converter's commercially available equipment. All of the co packers must be able to adapt to this new packaging and gain acceptability. The co packers were given feedback on the filling and the packing of the MREs into the fiberboard shipping containers. Also, the co packers performed end item inspection and issued a certificate of conformance for the Board of Veterinary to review. A success criterion does depend on the acceptability and conformance.

4.0 SITE/PLATFORM DESCRIPTION

4.1 TEST PLATFORMS/FACILITIES

NSRDEC is the selected facility for the tests shown in Table 12.

Table 12. Tests Performed at NSRDEC for Storage Testing

U.S. Army NSRDEC Facility
Microbial Validation
Water Content / Water Activity
Lipid Oxidation
Burst Strength
Oxygen Concentration
Sensory Testing
Recycling
Drop and Vibration Testing

4.1.1 NSRDEC is located in Natick, Massachusetts where most of the testing took place in the engineering and development buildings where the pertinent apparatus for the demonstration were located. NSRDEC has state of the art calibrated equipment and clean laboratories for the demonstration. There are controlled environment chambers for the storage study. The chambers are controlled and monitored and undergo an internal safety inspections on a quarterly basis. NSRDEC laboratories performed many of the microbiological and analytical methods to insure the food safety and evaluate pouches and meal bag for potential recyclability. In addition, the MRE was evaluated for vibration and drop tests in the packaging laboratory at NSRDEC. All laboratories comply with safety procedures and regulations. All scientists performing the tests are trained and experts in the relevant area. For sensory studies, there are several trained employees at NSRDEC for conducting taste testing. NSRDEC targets in-house employees or soldiers in the field for affective measures and trained-in-house employees for the other measures. When in-house measures are made, we try to control variables and focus on product in a CLT (central location testing).

4.1.2 Insect Testing Insect Testing was conducted with MBL at a 3500 sq. ft. warehouse facility in South Carolina. The following is a description of the facility.

- 900 sq. ft. office space divided into an office, conference room, bathroom and reception area
- 2,600 sq. ft. of insect testing space that includes:
  - 5 - 8x6 ft. environmental chambers
  - 1- 16x8 ft environmental chamber
  - 1 - 4x4 ft. environmental chamber
  - 2- Precision upright environmental cabinets
- MBL initiated the process of obtaining GLP certification.

MBL was chosen for the insect infestation studies as the entomologist, Mr. Jade Vardeman, has expert experience in this field and was a student of Mr. Michael Mullen who has routinely performed insect testing for MREs for the past 20 years. Mr. Mullen is also a consultant to MBL. Environmentally controlled, walk-in testing chambers provides an excellent testing arena that controls physical factors such as temperature, humidity and light which can affect experimental data. The parameters of the test are set at a range that is optimal for the development of the insects. MBL's facility was designed to support the operation of multiple large chambers.

4.1.3 Assembler. AmeriQual was the facility selected for filling and packing the MREs for this demonstration. The AmeriQual Group was chosen among the three MRE contractors due to past collaboration with them for the SERDP project. AmeriQual was chosen since the NSRDEC PI has worked them in the past on the SERDP 1479 project. AmeriQual Group filled and packed the non-retort and retort pouches with pretzels and penne pasta, respectively. This group has a quality control group that worked closely with NSRDEC to execute this portion of the project. Their facility has the Veterinary Board located at the facility that handled their conformances. This company communicates well and is an outstanding company to work with. AmeriQual is responsive and knowledgeable of this type of demonstration plan. The Quality Assurance Manager has been involved in the project and is familiar with all criteria for failures

4.1.4 Field Test - Fort McCoy is an active United States Army installation. It is located on 60,000 acres (240 km²) between Sparta and Tomah, Wisconsin, in Monroe County. Since its creation in 1909, the post has been used primarily as a military training center. Today Fort McCoy serves as a Total Force Training Center. Around 100,000 members of the military are trained at the fort every year, and the total number has exceeded 149,000 in the past. [6] The field study is chosen based on the environment (hot and humid) and the availability. This site was Fort McCoy, Wisconsin for August, 2009. This base supports the infrastructure to execute a field study.

4.1.4 Transportation/Distribution - Fort Bliss is a United States Army post located in New Mexico and Texas. With an area of approximately 1,700 sq mi (4,400 km^2), it is the second largest installation in the Army. Fort Bliss maintains and trains several U.S. Patriot Missile Batteries. Between 2008 and 2011, elements of the U.S. 1st Armored Division arrived at Fort Bliss to replace Air Defense Artillery (ADA) Brigades moving to Fort Sill, transforming Fort Bliss to a Heavy Armor Training post. Fort Greely is a United States Army launch site for anti-ballistic missiles located approximately 100 miles southeast of Fairbanks, Alaska. Several bases have been selected for the transportation/distribution study due to the wide range of environmental conditions that must be assessed for this study. The pallets were exposed to extreme heat and humidity conditions at Fort Bliss, and then shipped to Fort McCoy. Other pallets experienced the transportation route of high altitude and extreme cold conditions to Fort Greely.

4.1.5 Air Drop - Testing was conducted at Yuma Proving Ground (YPG) for high altitude drops as well as Rhode Island Aviation Facility for low altitude drops. Three major ranges (KOFA, Laguna, and Cibola) are located on the YPG facility which allow for a unique set of testing environments. The Cibola range was the primary range used for airdrop testing due to its extensive test range equipped with video, electronic and optical tracking systems as well as a cargo preparation complex. YPG is the army's only facility for certifying airdrop cargo and ammunition loads. The combination of a new state-of-the-art Air Cargo Preparation Complex, essentially unrestricted airspace, and highly skilled engineers, technicians, and military riggers provide the most complete infrastructure within the DoD specifically geared toward the support of air delivery missions. The air drop facilities were chosen since NSRDEC has an air drop team and a hypobaric testing facility where the Meal Bags and pouches can be exposed to designated altitudes as a function of time. The Airdrop sites were chosen due to Richard Benny's (Division Leader, Aerial Delivery Equipment and Systems Division War fighter Protection & Aerial Delivery Directorate Team Leader) recommendation. The program needed high and low altitude testing and both are available at these sites. The altitude and climatic chamber at NSRDEC were chosen as these are state-of-the art facilities that are maintained by subject matter experts and available for the ESTCP project. Three sites have been selected for the altitude and air drop testing and are shown in Table 13.

Table 13. Air Drop Sites and Plans

Air Drop Tests	Location
Hypbaromic Testing	NSRDEC
Low Altitude Testing	Rhode Island Aviation
High Altitude Testing	YUMA Proving Ground

4.2 PRESENT OPERATIONS

Present operations for MRE packaging consist of a polyolefin meal bag and a multilayered polymeric pouch with foil as barrier for the food pouches. There are purchased by one of the three assemblers and then utilized in producing and packaging of the rations. The rations follow the military specification for performance requirements.

4.3 SITE-RELATED PERMITS AND REGULATIONS

All NSRDEC laboratories were inspected quarterly to comply with the safety procedures and policies governed by EPA and OSHA. For MBL, no special permits are required for this type of experiment. NSRDEC was not aware of any permits or potential regulations needed for the field study and the transportation/distribution study. All safety and regulations at the Army bases were adhered to NSRDEC abided by any safety regulations at all of the installations and sites.
YPG required permits for recorders and cameras. The appropriate forms had already been filed with YPG.

5.0 TEST DESIGN

5.1 SYSTEM DESIGN

The system was designed to utilize nanotechnology for the MRE components instead of the current foil based packaging as described in Section 3.

5.1.1 MRE Components

Table 14 addresses the various sample pouches for the testing being performed in conjunction with the storage study. The designated samples numbers are for each time the pouches are removed from the storage chambers. These numbers were determined from the ASTM standard method.

Table 14. Demonstration Tests at NSRDEC

TEST	**Sample Current Components Retort (# of pouches per pull)**	**Samples Nano Retort A**	**Sample Current Components Non-Retort** Pouch	**Samples Nano Non-retort**	**Performer and Location**
Microbial	5	5	-	-	C. Lee; NSRDEC
Sensory	5	5	5	5	A.Wright, NSRDEC
Moisture Content	8	8	8	8	J. Ratto, NSRDEC, G. Pigeon, C. Thellen
Water Activity	4	4	4	4	S. Cheney, D. Froio, G. Pigeon NSRDEC
Lipid Oxidation	3	3	3	3	Nicole Favreau, NSRDEC
Oxygen Concentration	8	8	8	8	Robin Altmeyer, AmeriQual
Internal Pressure	8	8	8	8	Robin Altmeyer, AmeriQual
Total into Storage for 1 pull	41	41	36	36	
Total Samples for 20 pulls	820 pouches	820 pouches	720 pouches	720 pouches	

Table 15 also gives the number of meals for a designated test. Five hundred and seventy six meals are in a pallet of MREs. The number of samples is broken down for each test.

Table 15. Demonstration Tests

***Note that these samples were packed and assembled with corrected Meal Bag**

TEST	**Sample A Current Components Meal Bag, Retort and Non-Retort Pouch (# of samples)**	**Sample D GL KN Nano Meal Bag (6 mil) Nano Retort A and Nano non-retort (# of samples)***	**Samples C GL KN Current Components Meal Bag (11 mil) Nano Retort A and Nano non-retort (# of samples)**	**Samples B GL KN Neat Meal Bag (6 mil)Nano Retort A and Nano non-retort a (# of samples)**	**Performer and Location**
Insect Infestation	288	288	192	58	J. Vardeman; Moses Biologic
Rough Handling	288	288	240	96	J. Ratto; NSRDEC
Transportation/ Distribution	1728	1728	576	96	J. Ratto NSRDEC
Field Study	288	288	0	0	W. Johnson, NSRDEC
Air Drop	288	288	144		J.Niedzwiecki NSRDEC
Recyclability	12	12	0	0	J. Ratto, NSRDEC
Total Samples Needed	2892 (5 pallets and 1 case))	2892	1152	250	

5.2 LABORATORY TESTING

This section provides detailed description of the experimental design which includes the testing and evaluation of current MRE packaging components and nanocomposite packaging at a variety of storage conditions.

5.2.1 Assure Shelf Stability

5.2.1.1 Microbial Validation

Five samples for microbiological testing were randomly selected from container/pouches previously subjected to incubation testing. These samples were tested individually for aerobic plate counts for 48 hours at 35ºC and yeast and molds counts for five days at 25ºC.
Results were logged into the File Maker Pro 6 software to obtain a Microbiological Analytical Laboratory report. Average values were reported with a standard deviation.

5.2.1.2 Water Content/ Water Activity

Calibration for the balances used in the weighing of the pouches as well as for the water content and water activity is in the inspection and calibration program at NSRDEC. The company is contracted to check each balance on a yearly basis. The calibration procedure for balances is to use a known weight sample to determine the precision of the balance. The metric is the quantity of water contained in the food samples expressed as a percentage, where 0% is a dry sample. Moisture weight loss of food products is determined by drying the food in a vacuum oven and then reweighing. Water content of 3-5% is the success criteria. Water activity is a unitless value and the success criteria need to be between 0.1-.5.
The water activity apparatus has known salt solutions that the equipment is calibrated against before a sample is tested. This is performed each time a value is obtained. The equipment needs to be checked prior to use with Decagon's Verification Standards. These standards are salt solutions that have a specific modality and water activity. Verification checks can alert to contaminated sensors. For this study 1.000aw distilled water and 0.984aw (0.5 m KCL) are used.

5.2.1.3 Lipid Oxidation

The aldehyde, hexanal, was monitored throughout the duration of the storage study to measure the level of lipid oxidation that occurred in the penne and pretzel samples. Hexanal is a secondary lipid oxidation compound that can be used to measure the overall quality of the food, as well as the occurrence of lipid oxidation. A hexanal standard was purchased from Sigma Aldrich and run with each storage pull sequence. The sensory threshold for hexanal is 1-5 ppm, and a 1 ppm standard was run with each pull.
The hexanal was extracted from the samples with solid phase microextraction (SPME) and measured with an Agilent 6890/5975 gas chromatography/mass spec (GC/MS). The SPME fiber assembly was a Carboxen/Polydimethylsiloxane(CAR/PDMS) needle size 24 gauge with a coating of 75 μm. Prior to sampling, the samples were incubated for 600 seconds, at 65˚C with constant agitation. The extraction time was 1200 seconds and the desorption time was 300 seconds. The GC/MS was equipped with a CTC CombiPal SPME autosampler that allowed for the extraction and desorption to be performed automatically. The oven of the GC had an initial

temperature of 30˚C and a ramp up of 40˚C/minute to a final temperature of 240˚C. The front inlet was set to splitless mode at 235˚C with helium as the carrier gas. A GC Supelcowax 10 capillary column was used for the analysis.

The hexanal standard was used to determine the retention time and spectra of hexanal so that the peak of interest could be detected in the chromatogram for each storage pull. Throughout the storage study, the amount of hexanal did not vary significantly between the control samples and the test variables.

5.2.1.4 Burst Test

Internal pressure testing using a Lippke 2500 SL was performed for 8 samples at each storage pull temperature and time. The success criteria was met as there was 100% of the non-retort pouches exhibit no rupture or seal separation greater than 1/16 of an inch.

5.2.1.5 Oxygen Concentration

The sample size for oxygen is 8 pouches for each test. The military specifications dictates that the sample size is 8, but it is not based on the ANSI tables like the other end item exams. Data analysis is based on the MIL-PRF-44073F performance specification. Therefore, if one sample deviates from the specification result required for the test, then there is a failure of the entire lot.

The level of oxygen in the package is assessed for the packaging after the pouches are removed from the storage study and have undergone exposure to different environments. Standard statistical methods were employed with the data collection. Mean average values are reported. Oxygen concentration was at 0 ppm for the control and non-retort nanocomposite packaging during all the entire storage study at all temperatures and time periods. AmeriQual generated this data using 8 samples per pull.

5.2.1.6 Acceptance of Food From Sensory Panel

This objective is to determine the acceptability of the food from the sensory panel. Samples were prepared and stored for various time intervals and at various temperatures. Testing was done in real time over the period of 36 months. Accelerated shelf life measures (100^{o} and 120^{o} F) were completed in 6 months and 4 weeks respectively.

Sensory evaluation is important for the demonstration/validation study since this is a trained panel who evaluates the packaging with respect to ease of opening, performance and appearance, and food products with respect to flavor, taste, odor and texture. The metric is the number that is given as a rating on the surveys. The data requirement involves panel evaluation forms and questionnaires throughout the storage study. The success criterion is greater than 5.0 on the hedonic scale with 90% acceptance. Retortable and non-retortable pouches offer a protective barrier to foods after processing. Non-retortable barrier treatment (“Non-retortable Nano”) and retortable treatments (“Retort GL/K-N nano”) were evaluated. MRE counterparts (Non-retortable and Retortable) served as controls. This report’s purpose is to share information discovered from 30 months of research on three protective barriers. Each barrier was compared with its MRE control material counterpart using a two-sided Dunnett’s T-test with the MRE material serving as the control category. The most significant difference was found to be for pretzels stored at 40^{o} F.

Two types of sensory panels were conducted: (a) Technical panels and (b) Consumer panels. The former consisted of trained panelists evaluating the products for quality in five domains: (1) Appearance, (2) Flavor, (3) Odor, (4) Texture, and (5) Overall. The trained panels (referred to as "tech panels") use a 1-9 point sliding scale. Lowest quality ratings are a '1' and highest quality ratings are a '9' along a continuum. Trained panelists generally rate acceptable quality at a 7 on most products.

Samples were tested in randomized mono-sequential form using a modified Spectrum approach in climate controlled individualized booths in a CLT. Panelists were provided test results throughout the process and at the conclusion of each panel they were given statistical feedback to compare their individual data with the group data. 1x and 2x SD variances are highlighted. SIMS2000 Excel Stat and SAS software was utilized to collect and analyze the data. Panelists also provided descriptive feedback using a comments section for each attribute.

The consumer panels (employee consumers), focused on one domain—liking/disliking. The panelists rated subjectively the products using a Labeled Affective Magnitude scale (LAM) with highest possible liking scores of 100 and lowest possible disliking scores of -100. LAM ratings are purely subjective with no "right" or "wrong" rating whereas trained panelists are to objectively assess sensory properties in the aforementioned categories.

In sensory shelf-life determinations, the ASTM E 2454 is implemented with all 3 test methods described there (1-Discrimination, 2-Descriptive, and 3-Affective). NSRDEC's tech panelists are trained in the Spectrum™ approach. Attribute intensity measures, Degree of Difference (DOD), and Difference From Control (DFC) measures are also employed with discrimination tests. Horizontal line scales include JAR -50 to +50, DFC 0 to +10, SLAM -100 to +100, and Intensity 0 to 15+. Consumer (affective) data is generally collected with either a 9-point Hedonic or -100 to +100 LAM scale. NSRDEC generally targets in-house trained employees or soldiers in the field for affective measures.[7] When in-house measures are made, NSRDEC controls variables and focuses on product in a central location testing. (CLT). Field data may include environmental and other contextual elements that impact evaluations.

Data was collected electronically using SIMS2000 (Sensory Information Management Software) under controlled conditions in a central location testing facility (CLT) at NSRDEC in Natick, MA. Target sampling plans called for 9-12 trained panelists and 36+ consumer panelists per respective test.

Analyses were performed using SIMS2000, SAS, MS Excel, and XLSTST statistical analysis tools. ANOVA (analysis of variance) and means comparison were performed. For the two sample comparisons, MRE vs. treatments, a Dunnett (two-sided) analysis (XLSTAT) of the differences between the control category (MRE) and a treatment category were performed to determine if the treatment was significantly different from the control. When multiple means were compared, a Duncan's Multiple Range Test (SAS) was performed to determine which samples were significantly different. Confidence intervals (95%) were reported and derived from SIMS2000 and SAS. Graphs were prepared in MS Excel.

For the statistics, standard statistics (mean, SD, min, max, standard error, and variance) and NSRDEC performed a few post hoc tests such as a comparison of the means with either a Duncan's or Tukey's HSD or both. Furthermore, base line were used as a control value or if samples are sufficient, use the current component each time to act as a reference point from which we can perform a Dunnett's test for significant difference from the current component.

5.2.2 Assure Recyclability

5.2.2.1 Meal Bags

The average melt temperature of the Meal Bags were determined first to see if the melt temperature is in the range for recycling and to determine that the polymer remelts. ASTM D3418[7] method states that three samples should be performed and inter laboratory studies have performed round robin testing to determine the accuracy and precision of this method. Standard error bars were used to test for significant differences in the values. The success criterion is if the Meal Bag's measured melt temperature is in the range of 115 ± 10°C.

The melt temperature of the Meal Bags was determined by Differential Scanning Calorimetry (DSC). Reprocessing of the Meal Bag also occurred to determine recyclability. At NSRDEC, a grinder was used to make Meal Bags into regrind form which then is able to be processed. The regrind was in the form of shredded plastic. Flint Hills 1031 Neat LDPE was used as a control but also compounded with the Meal Bag regrind to create the films. Each test run comprised different concentration of regrind and LDPE to test the recyclability.

The experimental conditions utilized a DSM™ Explore Micro Compounder a co-rotating extruder which compounded the LDPE and regrind material. There is a pneumatic feeder which injected sample into the DSM™ take off roll and torque roll. This is used to collect the sample as it is extruded out of the die.

The testing process included: preparation, processing and collection/analysis. The investigation began with the preparation of a 12 gram sample that was inserted into the DSM™ by a pneumatic feeder and upon injection the instrument was sealed up. Once sealed, the feed were circulated throughout the instrument for a minute before it was processed out onto the rolls. The screws ran at 100 rpms and the temperature was adjusted to meet the processing requirements for the regrind material as the sample was extruded out of the die and onto the torque rolls cool air were shot onto the film acting as a coolant for the film. The torque roll ran at 50 rpms, while the take off roll ran a 750 rpms.

Samples were prepared using different compositions of material for each sample run. This tested the extent of recyclability of the material. Sample concentrations were broken down to weight percents of 12 grams by the following: 100/0, 80/20, 50/50, 20/80, and 0/100. These reflect the percent weights of LDPE to regrind. Each sample was tested to see if the film could be processed using the DSM™. If a run was unable to be processed onto the rolls, it was considered to be non-recyclable at the specific testing criteria.

The recycling company TREX evaluated the suitability of 2 MRE films for introduction into the recycled PE stream. These films were identified as "Control" and "Nano".

TREX evaluated both films in relation to our typical reprocessed PE product and at 25% and 50% inclusion in the typical reprocessed PE stream. The testing included DSC evaluation, melt flow testing, rheometer testing, color and ash content.

DSC testing was performed to evaluate the melting characteristics of the polymer. The data is also useful in determining processing suitability in the TREX process. Melt peak (melting point) was around 126°C with an onset temp of 117°C. These are typical values for most LDPE/LLDPE film encountered in the recycled PE stream at TREX

5.2.3 Insect Infestation The objective of this assay test was to assess the penetration resistance of Meal Bags. A criterion for success is that there is less than 20% percent. Replications are to be carried in rounds of four 12 week experiments.
The insect model is the cigarette beetle and the Meal Bags were:

(1) Control Meal Bag
(2) Nanocomposite Meal Bag

Thirty pouches (2” x 4”) were fabricated from each Meal Bag. Each pouch was filled with 50 grams of stored-product insect diet. The diet was a mixture of ground dog food, brewer's yeast and powdered milk. All pouches were placed inside three storage totes with each tote representing a film type. Once all the pouches were placed inside of each respective tote, 100 grams of insect diet was evenly spread over the pouches in each tote. After adding the additional insect diet, 100 cigarette beetle adults were added to each tote and the totes was sealed and placed in a testing chamber at 80°±5° F and 60±5% relative humidity. This test was run for 45 days.

5.2.4 Assure Integrity of Non-Retort Pouch After Environmental Rough Handling

This objective of this test is to determine that the MREs retort pouch withstands rough handling at different environmental conditions. This is important for the demonstration as the MREs experience abusive handling before arriving at their final destination. If the packaging has any defects then the food safety could be in jeopardy. The metric was the percentage of defects. MREs were tested using the following methods, D999-07 (Methods for vibration of shipping containers), and D-5276-98 (Test Method for drop test of loaded containers) where the samples were conditioned at low, standard and high temperature conditions according to MIL-PRF-44073F. Inspection of the pouches after the testing for leaks was recorded and failure rates were determined. The success rate would be less than 15% failure.

NSRDEC follows the vibration and rough handling methods outlined in ASTM methods.[8],[9],[10], The sample size is 24 cases of MRE for all tests at a variety of conditions. For the ASTM D-5276 drop test procedure, the procedure recommends that at least three samples be selected for evaluation. Data analysis consists of recoding damage to the contents or packaging. A mean failure height is determined and then the mean and the estimated standard deviation and level of confidence can be reported. ASTM D-4728, random vibration test method, requires that the test be done with replicates. Results of this test are descriptions and photographs of defects as defined in MIL-PRF-44073F. This test is non-quantitative so data analysis was conducted by comparing defects to the existing technology. Inspection results of the Meal Bags after the testing were recorded and failure rates were determined. The success rate would be less than 15% failure. This is a simulation of transport conditions where 36 samples were conditioned at two different temperatures for 72 hours prior to testing: -17° F and 100° F. A drop tower with 21 inch drop height with 10 drop sequence was performed and then the samples were placed on the vibration table at 268 cycles / minute at 1 hour test period. The Meal Bags were then inspected for major and minor defects after testing A Major Defect is defined as "likely to result in failure or reduce the usability of the product for its intended use" (Examples are Pinholes, Cuts, and Tears). A Minor Defect is defined as"Not likely to reduce the usability of the product or departure from established standards for effective use" (Examples are Stress Whitening, Dimples, Partial Bursts, and Abrasions). Definition for defects was taken from ACR-M-029.

5.2.5 Assure MRE Can Withstand Distribution / Transportation Study

The objective of this test is to determine the survival of the MREs after transportation and distribution. The MREs were subjected to extreme environmental conditions, and a rigorous transportation route which was relevant for this demonstration plan to assure survival in all types of distribution and transportation scenarios. An official inspector was needed to evaluate the packaging for defects after the MREs underwent the various distribution and transportation scenarios. A 20% failure rate was considered acceptable for this objective. Rigorous types of transportation and distribution (elevation, heat, cold, humidity, and dryness), rough handling and air drops were conducted. The packaging was inspected and tested after a variety of treatments. The soldiers were surveyed on the package integrity, ease of use and food quality in comparison to current component MREs.

5.2.5.1 Pira Distribution Study

Two full pallet loads of MRE rations were evaluated and inspected at Pira International in Lansing, Michigan. Distribution simulation and packaging inspections were conducted to evaluate and validate the overall system performance of the nanocomposite ration packaging. Simulations followed ISTA 3E testing procedures for unitized loads containing nanocomposite food pouches and control pouches and provided baseline data for ration performance and survivability during material handling and simulated transport activities. Laboratory simulations conducted during the trials included horizontal impact, rotational edge drop, compression, and random vibration with each test evaluating the system performance of each unit load. The purpose of this testing was to simulate distribution conditions for worldwide transportation and storage. The test sequence followed ASTM D4169, Distribution Cycle 18 Assurance level II.

5.2.5.1.1 Package Validation and Pre-Shipment Testing

Pre-shipment testing or distribution testing involves controlled and objective assessment of packaging and product performance in the Package Testing Laboratory. This testing evaluates the response of packaging and product to the hazards and rigors of the distribution and shipping environment. This test/evaluation was critical in determining whether or not the prototype nanocomposite packaging can withstand rough handling conditions outlined in ISTA 3E testing for unit loads of same product.

ISTA test procedure 3E is a general simulation performance test for unitized loads comprised of multiple products or packages of the same products. The distribution and transportation study followed an International Transit protocol.[12] As shown in Table 16, the ISTA test 3E was used to evaluate the protective performance of packaged products and load stability under the normal stresses encountered during handling, storage and transportation. ISTA 3E evaluates the protective performance of packaged product related to vibration, shock, and other stresses typically encountered in the handling and transportation process, as well as load stability

ISTA 3E unit load testing and inspection of MRE nanocomposite packaging that has been subjected to over the road shipment from AmeriQual Packaging to testing center in East Lansing, MI was conducted. Multiple loads of MREs were evaluated and inspected at Pira International package test center and followed inspection guidance detailed in DSCP document 4155.2, App A. Data recorders were recovered within the two test pallets of MREs and transportation data was downloaded and organized on site. On two consecutive days the test samples were subjected to rough handling events and then test samples were inspected for package failure modes. In total, 1128 MRE rations were inspected and a total of 3384 individual components of retort, non-retort and meal bag were inspected for failure.

Prior to shipment, the SAVER 9X30 environmental recorders were mounted and programmed to capture comprehension data involving shock (impact/drop), vibration, temperature and humidity conditions during transport. The nanocomposite packaging prototypes traveled from AmeriQual Packaging (Evansville, IN) to Pira International in Lansing, MI. Transportation data obtained from the shipment was used for supplementary in-lab assessments of military packaging and to further define the distribution environment.

Table 15. ISTA 3E Test Sequence.

Sequence #	Test Category	Test Type	Test Level
1	Atmospheric Preconditioning	Temperature / Humidity	Ambient Laboratory Conditions
2	Shock	Horizontal Impact	42 inches per second
3	Shock	Rotational Edge Drop	8 inch
4	Compression	Machine Apply / Release	Calculated Test Force x 1.4
5	Vibration	Random	Overall G_{rms} level of 0.54
6	Shock	Rotational Edge Drop	8 inch

5.2.5.1.2 Unit Load Packaging

All test units evaluated under the ISTA 3E test consisted of fully packaged MRE containers as a palletized product. Each unit load was constructed at AmeriQual Packaging under normal ration assembly procedures in accordance with type I, class C of DLA Troop Support Form 3507, Loads, Unit: Preparation of Semiperishable Subsistence Items. The configuration of the unitized load followed Type I, Class C requirements which included film wrapping, non-metallic strapping and a unit load fiberboard caps with an extended flange on two sides of the unit load as shown in Figure 6. The pallet cap was constructed from fiberboard conforming to V3c or V2s of ASTM D4727 with two flanges across the width of the unit load which was placed on the top layer of the unit load and secured by the primary and auxiliary straps positioned across the width. The non-metallic straps were tensioned to indent the edge of the cap without tearing the edge of the cap. Additionally, each unit load was secured with a 90 gauge (.9 mil thickness) PE stretch film to include multiple wraps, overlapping edges and full coverage of the unit load. The pallet layer configuration consisted of a three by four pallet pattern arranged on the wooden pallet with twelve containers uniformly arranged on the pallet. The pallet pattern was repeated throughout the four layers, forming a column stacked unit load. The pallet overhang was evenly distributed across both dimensions of the pallet. In normal assembly operations each load had forty-eight containers with 24 of them containing menus 1-12 and labeled as case “A” and the remaining 24 cases containing menus 13-24 and labeled as case “B”. For the test units used during testing, all samples consisted of a single ration (Penne Pasta) for both the control and nanocomposite test samples. As shown in Table 17, each unit load had outside dimensions of 51 inches in length, 44 inches in width and an overall height of 42 inches with an overall cubic volume of 54.5 cubic feet. Each test unit remained within the unit load maximum dimensions of 53 inches in length, 44.75 inches in width and 43 (+1 in.) in overall height. The overall weight for each unitized load totaled 933 lbs for the control test unit and 953 lbs for the nanocomposite test unit. The fully loaded pallet with forty-eight secured ration cases was considered as one test unit.

.

A)  B) 

Figure 6. A) Nanocomposite Unit Load Configuration. B) Control A Unit Load Configuration.

Table 16. Unit Load Description.

Test Sample	Length (in)	Width (in)	Height (in)	Cubic Feet (ft^3)	Weight (lbs)	Containers
MRE Control	51	44	42	54.5	933	48
MRE Nanocomposite	51	44	42	54.5	953	48

5.2.5.1.3 Horizontal Impact Test: Pallet Marshalling Impacts

As shown in Figure 7, each unitized load was placed on the horizontal impact sled with the test load being placed in contact with the impact surface prior to each test. The impact sled was configured to stop using a half-sine acceleration pulse with a velocity change of 42 in/s. Each unit load was impacted on all four sides of the pallet per ISTA Procedure 3E.

Figure 7. Test Sample in Horizontal Impact Test Orientation.

5.2.5.1.4 Vertical Impact Test: Rotational Edge Drops - 1st set

This method consists of setting one end of the unitized pallet on a four inch rigid support and then the opposite end was raised 8 inches using a forklift as shown in Figure 8. The supports on one end were then pulled out which allows the pallet to fall on its edge. Two adjacent sides of the pallet were dropped in accordance with ISTA Procedure 3E.

Figure 8. Test Sample in Rotational Edge Drop Test Orientation.

5.2.5.1.5 Vibration Test: Random Vibration; Pallets were Double Stacked

A vibration table complying with the test apparatus section of ASTM D 4728 was used and is shown in Figure 9. The samples were placed on the vibration table and the samples secured in a fixture to resist horizontal motion, but, without restricting vertical motion. The table was programmed with the power spectral density profile defined by ISTA Procedure 3E. The samples were vibrated for 120 minutes with Control A on the bottom and then switched and vibrated for 120 minutes with GLKN on the bottom.

Vehicle Vibration. The test method and levels for this schedule were intended to determine the ability of shipping units to withstand random vibration during transport. For this section of the test plan, each pallet load was fitted with another pallet in a double-stack configuration. The top pallet was loaded with a concentrated dead weight load equal to the weight of the lower pallet. This simulated a double stack of units in transport. For vertical vibration, the test was conducted for 3 hours on a vertical motion vibration machine. If transverse and longitudinal vibrations are possible causes for damage, vibration testing on a horizontal motion vibration machine for 3 hours in each axis is typically conducted.

Figure 9. Test Samples in Vibration Test Orientation.

5.2.5.1.6 Vertical Impact Test: Rotational Edge Drops - 2nd set

Rotational edge drops were performed as described in 5.2.5.1.5.

5.2.5.1.7 Static Compression Test

Unit load compression used to simulate warehouse stacking was conducted in accordance with ASTM D642, *Standard Test Method for Determining Compressive Resistance of Shipping Containers, Components, and Unit Loads*. The test levels and the methods for this section of the test protocol were intended to determine the ability of the ration container to withstand the compressive loads that occur during warehouse storage. The minimum required load was calculated by the following formula, TL = W_t x (S-1) x SF x 1.4, where TL = Calculated Test

Load (lb), W_t = Total weight of packaged product (lb), S = Total number of packaged products in stack and SF = Safety Factor (Note: A safety factor of 3 was used during unit load compression). In addition to evaluating the containers under loading conditions, the test also identifies the product protection level for each individual meal bag.

As shown in Figure 10, a compressive force was applied to the unit load containing 48 ration cases assembled in accordance with ration assembly requirements. The test equipment subjected the test unit to a constant load in the top-to-bottom orientation of the unit load. At a rate of 0.5 inches per minute, using a floating platen; each unit was tested until the calculated static load of 12,008 lbs was reached. Once the calculated load was reached the platen was immediately removed from the unit load.

Figure 10. Compression Applied to MRE Unit Load.

Quality assurance samples were collected for each case. The sampling protocol allowed for enough samples to obtain a statistical analysis. All subject matter experts were notified and asked for the numbers of samples with quality assurance being considered. There are over 7 pallets of current components that were used throughout the study. Two and a half pallets of MREs were with the nanocomposite meal bag and nanocomposite non-retort and retort pouch. There were 4 pallets with the nanocomposite non-retort and retort pouch in a current components meal bag. There is 1 pallet of MREs with the 6 mil non-nano control and nanocomposite non-retort and nanocomposite retort pouches. All retort pouches contain penne pasta and all non-retort pouches contain pretzels.

5.2.6 Field Test

5.2.6.1 Soldier Acceptance of Food and Packaging

This is a qualitative measure in that the soldiers filled out questionnaires on the food in the packaging as well as packaging integrity. The results are based on 100 soldiers. Questions were designed by experts to obtain answers that can aid on the design and transition of this technology. This method was chosen based on the expertise of the behavioral scientists at NSRDEC that yearly evaluate the MRE for the soldiers on field studies.

The following provides an outline of the assessment data management techniques that were employed:

Questionnaires**:** Questionnaires were designed to capture the data requirement from each participant. The questionnaires consisted of rating scales, multiple choice questions, and write-in areas for open-ended comments. Quantitative questionnaire data was entered manually into SPSS (Statistical Package for Social Sciences) spreadsheets, and analyzed to calculate and report descriptive statistics. Frequency tables of responses were compiled for multiple choice questions, and mean rating scores were be computed for rating scale questions.

The questionnaires were designed to collect the following information:

- Ease of Use
- Taste
- Durability (field use)
- Mission/Task Acceptability
- Recommended Design Improvements

This qualitative objective was to obtain approval of the packaging from the customer, the soldier. This was relevant to the demonstration since the soldier is the designated customer of the rations and ration packaging. The soldier was involved in a field study using the nanocomposite packaging and surveyed on this packaging and the food products. The metric was the scaled scores from questionnaires. The data requirements were that the surveys must be filled out by the soldier and the individual scores were reported. The success criterion is that the average score was greater than 5.0 of the hedonic scale.

In June 2010 a field evaluation of the two proposed nanopackaging concepts was conducted at Joint Base Lewis-McChord, Washington, with 112 students enrolled in the Non Commissioned Officers Academy (Reserves).

Identical MRE menus were packaged under 3 packaging conditions. The current MRE packaging was used as a control, for comparison purposes. The retort pouch was the GL/KN nanocomposite packaging. The MRE meal bag was tested under all three conditions, as were the retort pouches (Spicy Penne Pasta), and the non-retort pouches (Pretzels). The MRE menu provided in all 3 conditions were foods currently available in MRE menus: the Spicy Penne Pasta entrée, and the pretzels.

MREs were issued in the morning by NSRDEC personnel. Over the 3 days of the evaluation, every soldier was issued each of the 3 packaging conditions. The soldiers carried the MREs in the field as usual, until it was time for their midday meal. They opened the packages, ate their meal, and completed the questionnaires. Alternate MRE entrees were available in the event that the packaging was damaged, or in the event that the soldiers were bored with being issued the same meal three days in a row. Before soldiers were offered the alternate entrees, they were asked to examine the packaging and to taste the foods they were issued in order to rate them on

their questionnaires (unless the packaging was damaged, in which case they were not expected to taste the food). Questionnaires were collected after lunch by Natick personnel. During this time, the students were taking part in regular exercises devised by the NCO Academy, and were living in the field for all of the evaluation days. The terrain was forested and the weather was mild and misty.
Before the field evaluation began, the participating soldiers were given a pre-briefing about the reason for the evaluation and how it was going to be conducted. At this time they completed a pre-evaluation questionnaire which collected demographic information, and were issued their first MRE and MRE questionnaire.

The field tests occurred at a designated base determined by NSRDEC. Pallets for MREs being stored at Fort Bliss, Texas, during the summer time high heat and transported through different elevations were then shipped to Fort McCoy. The training area was in temperate climatic region of the continental U.S. with daytime highs between 70 and 80 degrees. Soldiers participating in this final phase of testing transported the rations to the field site thus handled them in cases in the typical rough handling manner (i.e. cases thrown from soldier to soldier, thrown from the vehicle to the ground). All activities took place in the open including the consumption of the rations for lunch time meals. NSRDEC had a relevant field test operation occurring at the same time as the ESTCP demonstration. This is advantageous since the personnel are already there to work on the demonstration and evaluate/inspect the MREs.

5.2.6.2 Assure MRE Can Withstand Air Drop Transportation

This objective determined if the packaging can withstand air drops. Airdrop survival for the MRE is crucial with deployed soldiers. The metric was the percentage of failures from packaging seals and bursts. The data requirement was to exam all MRE components after air drops and altitude chamber testing to determine the percentage of failures. The success criterion was determined to be less than 12% failure rate.
Aerial delivery demonstrations of combat rations were performed in partnership with the Illinois Air National Guard, 182nd Airlift Wing in an effort to assess the overall survivability during aerial delivery operations. In total, nine pallet loads of test samples were prepared for aerial delivery operations and were fitted with standard equipment and ancillary cushioning for the aerial delivery demonstrations.

Several pallets loads were rigged with the nanocomposite packaging and the packaging was inspected and data were recorded for package integrity and airdrop survivability. Load configurations and testing information are shown in Table 18. Upon receipt of the containers at YPG, the MREs were inspected for any signs of physical damage. After air drops occurred, the samples were found and inspected at the drop zone in comparison to existing military packaging. This is a non qualitative test.

The Low Velocity airdrops were conducted with standard CDS procedures using a static line deployed pilot parachute to deploy the main G-12 E cargo parachute at 650 feet above ground level. The typical rate of descent for Low Velocity CDS with the G-12 E cargo parachute is 26-28 FPS and High Velocity 70-90 fps. To compensate for the difference in rate of descent between high velocity and low velocity airdrop the CDS bundles utilize a standard energy dissipation material of cardboard honeycomb. The energy dissipation material is cut in standard configurations for each type of airdrop being conducted.

5.2.6.2 .1 Sample Assembly

Table 18. Load Configurations and Testing Information.

Load #	Material			Low	High	Cargo	Altitude	Recorder #
	Nano	Control A	Control 7	Velocity	Velocity	Parachute	at Release (ft)	
1	X	X			X	HV CDS	2,000	Box 6
2	X	X			X	HV CDS	2,000	Box 4*
3	X	X			X	HV CDS	2,000	Box 1
4	X	X	X	X		G-12	600	Box 1
5	X	X	X	X		G-12	600	Box 2
6	X	X	X	X		G-12	600	Box 3
7	X	X	X		X	HV CDS	2,000	Box 3
8	X	X	X		X	HV CDS	2,000	Box 2
9	X	X	X		X	HV CDS	2,000	Box 5

*Box 4 was ejected from the load during delivery/parachute opening rendering the data invalid.

5.2.6.2.2 Low Velocity

Three unit loads (load 4, 5, and 6) were dropped during low velocity aerial delivery trials conducted at roughly 600 feet above ground level (AGL). Each load consisted of 48 MRE cases per unit load with 15 control cases, 15 nanocomposite cases, one data recorder case and 17 "dummy" cases used as void fill to build a complete unit load. The unit load layout and configuration, as shown in Figure 11Figure 11Figure 13 highlights the configuration of the unit load by layer which consisted of a 50% mix of both nanocomposite and control samples. The test samples for the low velocity airdrop trial were inspected at a rate of 75%, meaning that of the four cases per layer only three were inspected for visual defects. Of the cases that were selected for inspection all rations within the cases were inspected for visual defects in the meal bag, penne pasta retort pouch and non-retort pretzel pouch.

LOAD 4

LAYER 4 (TOP)

Recorder 4-1	Control A 4-2	Nano 4-3
Control A 4-4	Nano 4-5	Control 7 4-6
Nano 4-7	Control 7 4-8	KN 4-9
Control 7 4-10	Control 7 4-11	Control A 4-12

LAYER 3

Control 7 3-1	Control 7 3-2	Control A 3-3
Control 7 3-4	Control A 3-5	Nano 3-6
Control A 3-7	Nano 3-8	Control A 3-9
Nano 3-10	Nano 3-11	Control 7 3-12

LAYER 2

Control A 2-1	Control A 2-2	Nano 2-3
Control A 2-4	Nano 2-5	Control 7 2-6
Nano 2-7	Control 7 2-8	Nano 2-9
Control 7 2-10	Control 7 2-11	Control A 2-12

LAYER 1 (BOTTOM)

Control 7 1-1	Control 7 1-2	Control A 1-3
Control 7 1-4	Control A 1-5	Nano 1-6
Control A 1-7	Nano 1-8	Control A 1-9
Nano 1-10	Nano 1-11	Control 7 1-12

LOAD 5

LAYER 4 (TOP)

Recorder 4-1	Control A 4-2	Nano 4-3
Control A 4-4	Nano 4-5	Control 7 4-6
Nano 4-7	Control 7 4-8	Nano 4-9
Control 7 4-10	Control 7 4-11	Control A 4-12

LAYER 3

Control 7 3-1	Control 7 3-2	Control A 3-3
Control 7 3-4	Control A 3-5	Nano 3-6
Control A 3-7	Nano 3-8	Control A 3-9
Nano 3-10	Nano 3-11	Control 7 3-12

LAYER 2

Control A 2-1	Control A 2-2	Nano 2-3
Control A 2-4	Nano 2-5	Control 7 2-6
Nano 2-7	Control 7 2-8	Nano 2-9
Control 7 2-10	Control 7 2-11	Control A 2-12

LAYER 1 (BOTTOM)

Control 7 1-1	Control 7 1-2	Control A 1-3
Control 7 1-4	Control A 1-5	Nano 1-6
Control A 1-7	Nano 1-8	Control A 1-9
Nano 1-10	Nano 1-11	Control 7 1-12

LOAD 6

LAYER 4 (TOP)

Recorder 4-1	Control A 4-2	Nano 4-3
Control A 4-4	Nano 4-5	Control 7 4-6
Nano 4-7	Control 7 4-8	Nano 4-9
Control 7 4-10	Control 7 4-11	Control A 4-12

LAYER 3

Control 7 3-1	Control 7 3-2	Control A 3-3
Control 7 3-4	Control A 3-5	Nano 3-6
Control A 3-7	Nano 3-8	Control A 3-9
Nano 3-10	Nano 3-11	Control 7 3-12

LAYER 2

Control A 2-1	Control A 2-2	Nano 2-3
Control A 2-4	Nano 2-5	Control 7 2-6
Nano 2-7	Control 7 2-8	Nano 2-9
Control 7 2-10	Control 7 2-11	Control A 2-12

LAYER 1 (BOTTOM)

Control 7 1-1	Control 7 1-2	Control A 1-3
Control 7 1-4	Control A 1-5	Nano 1-6
Control A 1-7	Nano 1-8	Control A 1-9
Nano 1-10	Nano 1-11	Control 7 1-12

Figure 11. Low Velocity Test Load Configuration of Samples by Layer.

LOAD 7

LAYER 4 (TOP)

Recorder 4-1	Control A 4-2	Nano 4-3
Control A 4-4	Nano 4-5	Control 7 4-6
Nano 4-7	Control 7 4-8	Nano 4-9
Control 7 4-10	Control 7 4-11	Control A 4-12

LAYER 3

Control 7 3-1	Control 7 3-2	Control A 3-3
Control 7 3-4	Control A 3-5	Nano 3-6
Control A 3-7	Nano 3-8	Control A 3-9
Nano 3-10	Nano 3-11	Control 7 3-12

LAYER 2

Control A 2-1	Control A 2-2	Nano 2-3
Control A 2-4	Nano 2-5	Control 7 2-6
Nano 2-7	Control 7 2-8	Nano 2-9
Control 7 2-10	Control 7 2-11	Control A 2-12

LAYER 1 (BOTTOM)

Control 7 1-1	Control 7 1-2	Control A 1-3
Control 7 1-4	Control A 1-5	Nano 1-6
Control A 1-7	Nano 1-8	Control A 1-9
Nano 1-10	Nano 1-11	Control 7 1-12

LOAD 8

LAYER 4 (TOP)

Recorder 4-1	Control A 4-2	Nano 4-3
Control A 4-4	Nano 4-5	Control 7 4-6
Nano 4-7	Control 7 4-8	Nano 4-9
Control 7 4-10	Control 7 4-11	Control A 4-12

LAYER 3

Control 7 3-1	Control 7 3-2	Control A 3-3
Control 7 3-4	Control A 3-5	Nano 3-6
Control A 3-7	Nano 3-8	Control A 3-9
Nano 3-10	Nano 3-11	Control 7 3-12

LAYER 2

Control A 2-1	Control A 2-2	Nano 2-3
Control A 2-4	Nano 2-5	Control 7 2-6
Nano 2-7	Control 7 2-8	Nano 2-9
Control 7 2-10	Control 7 2-11	Control A 2-12

LAYER 1 (BOTTOM)

Control 7 1-1	Control 7 1-2	Control A 1-3
Control 7 1-4	Control A 1-5	Nano 1-6
Control A 1-7	Nano 1-8	Control A 1-9
Nano 1-10	Nano 1-11	Control 7 1-12

LOAD 9

LAYER 4 (TOP)

Recorder 4-1	Control A 4-2	Nano 4-3
Control A 4-4	Nano 4-5	Control 7 4-6
Nano 4-7	Control 7 4-8	Nano 4-9
Control 7 4-10	Control 7 4-11	Control A 4-12

LAYER 3

Control 7 3-1	Control 7 3-2	Control A 3-3
Control 7 3-4	Control A 3-5	Nano 3-6
Control A 3-7	Nano 3-8	Control A 3-9
Nano 3-10	Nano 3-11	Control 7 3-12

LAYER 2

Control A 2-1	Control A 2-2	Nano 2-3
Control A 2-4	Nano 2-5	Control 7 2-6
Nano 2-7	Control 7 2-8	Nano 2-9
Control 7 2-10	Control 7 2-11	Control A 2-12

LAYER 1 (BOTTOM)

Control 7 1-1	Control 7 1-2	Control A 1-3
Control 7 1-4	Control A 1-5	Nano 1-6
Control A 1-7	Nano 1-8	Control A 1-9
Nano 1-10	Nano 1-11	Control 7 1-12

Figure 12. High Velocity Test Load Configuration of Samples by Layer.

Figure 13. Low Velocity Unit Load Configuration (3 Layers of Honeycomb)

5.2.6.2.3 High Velocity

Unitized loads were delivered from a C-130H aircraft via conventional parachute systems for low/high velocity delivery bundles, delivering from an altitude of 650 and 1,500 feet, respectively. T he unit load layout and configuration, as shown in Figure 12 highlights the configuration of the unit load by layer.

Figure 14. High Velocity Unit Load Configuration (5 Layers of Honeycomb)

The unit loads tested consisted of 48 cases assembled in accordance with normal assembly procedures. The samples were configured in a 3 x 4 pallet pattern with a column stack of four containers. Each load utilized a standard wooden pallet with additional honeycomb material positioned underneath the pallet for product protection during impact. As shown in Figure 14, the high velocity loads were fitted with 5 layers of honeycomb that fit the footprint of the wooden pallet.

The High Velocity airdrops were conducted with standard High Velocity CDS procedures utilizing a static line deployed 26' Ring slot parachute at 2000' above ground level. Figure 15 shows the transfer of loads being transferred to the C-130H.

Figure 15. High Velocity Loads Being Transferred from K Loader to C-130H.

5.2.6.2.4 Delivery

The aerial delivery of the MRE rations were characterized with the internal data recorders which helped identify and define four unique stages of the delivery process to include; 1) deployment, 2) parachute opening, 3) descent, and 4) impact. The four stages, as shown in Figure 16 represent significant levels of velocity change as each load exits the aircraft and descend to the landing zone. The initial deployment stage begins as the unit load exits the aircraft which is followed by a short free fall, prior to the opening of the parachute. Depending on the airflow each load encounters, the bundles would often rotate or spin as it impacts the airflow, deployment, of aerial delivery were identified during the demonstration and include cargo deployment, opening, descent and final impact at the landing zone. The deployment phase begins with the opening of the rear cargo door and ramp of the aircraft are opened just prior to release of the unit loads. Once the aircraft has identified the proper drop altitude, the aircraft would pitch slightly and the loads would fall out of the back of the aircraft from its own weight. Once the unit loads exit the aircraft each load went into an initial free fall lasting a few seconds where the parachute is still bundled.

Figure 16. Drop Sequence for Aerial Delivery (High Velocity Drop Sequence - 11/15/2010)

5.2.6.2.5 Data Acquisition

Each unit load was fitted with instrumentation prior to aerial delivery demonstration in an effort to characterize the dynamic forces encountered during aerial delivery and more specifically during low velocity and high velocity aerials delivery.

Environmental data recorders were integrated into each unitized load to better define the key environmental hazards; recording critical shock and vibration events during delivery and also capturing altitude, pressure, humidity, and temperature profiles during handling and demonstration of the test rations. Shock/Impact data collected from this study helped set baselines for aerial delivery methods and to help show the correlation between varying methods of aerial delivery and their resulting impact on ration survivability.

Figure 17 Field Data Recorders (SAVER9X on left and SAVER3M plus on right).

The demonstration and validation effort assessed the survivability of the nanocomposite packaging systems with a visual examination plan that executed inspection of over 3,400 rations. The examination of the nanocomposite meal bags, retort food pouches and non-retort food pouches were inspected and evaluated against the existing systems by representatives from the United States Department of Agriculture, highlighting material/packaging defects and root cause explanations of package failures.

The SAVER™ 9X30 field data recorder captures drops, impacts, vehicle motion and vibration. This self-powered Field Data Recorder provides 16 bit resolution on each of the 9 dynamic channels capable of recording for 30 days. It was used as the primary source for defining, characterizing, and visualizing aerial delivery of combat rations and the test environments. This instrument provides up to nine dynamic channels (3 internal and 6 external), while also recording temperature, humidity and atmospheric pressure. The 9X30 data recorder measured continuously throughout demonstration and houses an internal clock to mark the exact time when each event occurred.

The SAVER™ 9X30 and 3M30 PLUS field data recorders, shown in Figure 17, were used within each unit load to capture drops, impacts, vehicle motion, vibration and environmental conditions such as temperature, humidity, and atmospheric pressure (altitude). These self-powered Field Data Recorders were used as the primary source for defining, characterizing, and visualizing aerial delivery and the prevailing test environments.

The 3M30 PLUS allows the ability to internally record temperature, humidity, and atmospheric pressure (altitude) during both threshold and timer triggered sampling. The 3M30 PLUS also allows user defined sampling rate and filter frequency acquisition settings, while increasing the storage capacity for significant events. These instruments utilize Lansmont's SaverXware application software for all programming, analysis, reporting and archiving of instrument activities. The data recorders were positioned on the corner of each top layer of the unit loads, as shown in Figure 18.

Figure 18. Data Recorder Setup Configuration (MRE case with recorder was positioned on the corner of each top layer).

5.2.6.2.6 Fort Bliss Study

NSRDEC engineers supported the U.S. Army Veterinary Command (VETCOM) inspection of experimental nanocomposite MRE packaging, including the meal bag, retort and non-retort pouches, which were subjected to cross country shipment and storage in a warm weather climate. Three pallet loads of MRE rations were evaluated and inspected at Fort Bliss, Texas as shown in Figure 19Figure 19. The configuration of the packed and unitized rations are shown in Table 17. NSRDEC engineers with the assistance of qualified VETCOM inspectors evaluated the test samples. The inspection of these experimental MRE rations followed inspection guidance detailed in Defense Supply Center Philadelphia (DSCP) document 4155.2, Appendix A.

Figure 19. Representative Transport Route of Test MRE Samples.

Figure 20. Pallets at Fort Bliss

Table 17. MRE Ration Configurations

	Control A #2	C KN	Control A	C GL/KN	D GL/KN
Pallet Number	1	2	3	3	3
Number of Cases Shipped	48	48	31	7	7
Control Meal Bag	X	X	X	X	
6 mil Nanocomposite Meal Bag					X
Control Retort Pouch	X		X		
KN Retort Pouch		X			
GL/KN Retort Pouch				X	X
Control Non-Retort Pouch	X		X		
Experimental Non-Retort Pouch		X		X	X

As shown in Figure 19. Representative Transport Route of Test MRE Samples.Figure 19, three pallets of MRE rations were evaluated which contained 48 cases on each pallet. Figure 21 documents the shipping information for the three pallets of MRE rations, which were shipped via Yellow Freight. Upon arrival at Fort Bliss the MRE rations were stored in warehousing until 28 September 2009, for approximately three months of warm weather storage.

Seven cases from each pallet of MRE rations were inspected by VETCOM and NSRDEC engineers. Seven was determined to be the maximum possible number of cases available to inspect because seven cases of C GL/KN and D GL/KN MRE rations were included. VETCOM randomly selected four MRE rations from each case to inspect, while NSRDEC engineers inspected the remaining eight MRE rations.

The inspection plan is documented below:

1. Upon receipt of test containers, inspected for any signs of physical damage and reported findings

2. Selected seven cases from each pallet of each sample set of test samples and label accordingly
3. From each case VETCOM inspected four MRE rations and NSRDEC inspected the remaining eight MRE rations
4. VETCOM followed DSCP document 4155.2, App A for MRE ration inspection while NSRDEC engineers focused on the meal bag, retort and non-retort packaging
5. Failure rates were recorded for each sample set and pictures of representative failures were also documented, in addition representative failures were also kept

Nanocomposite packaging systems, for both retort and non-retort components, were filled at AmeriQual Foods in January 2009. The test samples were shipped via standard ground freight from AmeriQual Packaging and covered approximately 1,400 miles to their final destination. The examination plan followed document DSCP 4155.2, Appendix A, implementing a random inspection of three MRE unit loads.

5.2.6.2.6 Fort Richardson

The objective of this study was to evaluate experimental MRE ration packaging which were subjected to cross country shipment and storage in a cold weather climate. Three pallet loads of MRE rations were evaluated and inspected at Fort Richardson, Alaska by NSRDEC engineers with the assistance of qualified VETCOM inspectors. The inspection of these experimental MRE rations followed inspection guidance detailed in DSCP document 4155.2.

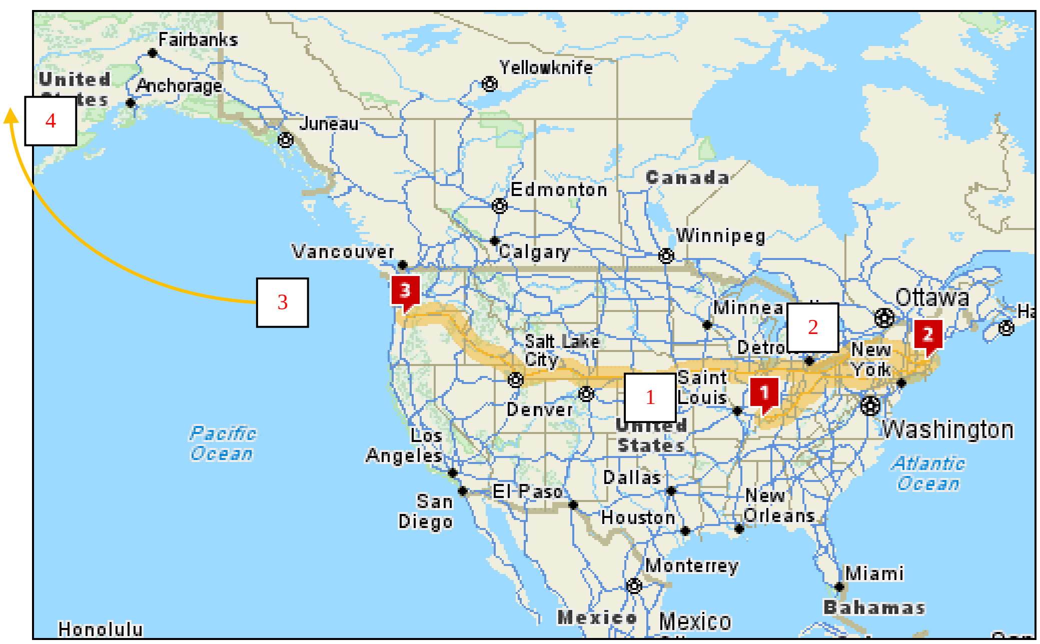

Figure 21. Representative Transport Route of Test MRE Samples. Location 1 is the starting point (AmeriQual) , shipped to location 2 (NSRDEC) and then to location 3 a storage warehouse in Portland Oregon. The three unit loads were then shipped to Anchorage Alaska by sea ferry, location number 4.

Several MRE ration configurations were evaluated and are displayed in Table 18.

Table 18. MRE Ration Configurations

	Control A #2	Control A	C GL/KN	D GL/KN
Number of Cases Shipped	48	31	7	7
Control Meal Bag	X	X	X	
6 mil Nanocomposite Meal Bag				X
Control Retort Pouch	X	X		
GL/KN Retort Pouch			X	X
Control Non-Retort Pouch	X	X		
Experimental Non-Retort Pouch			X	X

Three pallets of MRE rations were evaluated; two pallets contained 48 cases of rations while the third contained 45 cases of rations and three MRE ration cases containing the SAVER 9X30 Field Data Recorder and associated external accelerometers. The data recorder provided nine dynamic channels, three of which were internal and six external. The SAVER 9X30 was able to measure unattended and continuously for up to thirty days. Table 19 documents the shipping information for the three pallets of MRE rations, which were shipped via Yellow Freight. Upon arrival at Fort Richardson the MRE rations were stored in an outdoor ISO container until 12 April 2010, for approximately two months of cold weather storage.

Figure 22 SAVER9X30 Setup Configuration Set in the Mixed Pallet (#3).

Table 19. Ship Date and Location of Test Samples During Transport Study

Ship Date	Location	Transport Status
4 Feb 2010	NSRDEC Natick, MA	Ground
4 Feb 2010	YRC Terminal Shrewsbury, MA	Ground
6 Feb 2010	YRC Terminal Tonawanda, NY	Ground
8 Feb 2010	YRC Terminal Chicago Heights, IL	Ground
12 Feb 2010	YRC Terminal Portland, OR	Sea Ferry
16 Feb 2010	YRC Terminal Anchorage, AK	Ground

Seven cases from each pallet of MRE rations were inspected by VETCOM and NSRDEC engineers. Seven was determined to be the maximum possible number of cases available to inspect because seven cases of C GL/KN and D GL/KN MRE rations were included. VETCOM randomly selected four MRE rations from each case to inspect, while NSRDEC engineers inspected the remaining eight MRE rations. Figure 23 illustrates the locations of inspected MRE ration cases, as well as the location of the SAVER 9X30 field data recorder and external accelerometers,

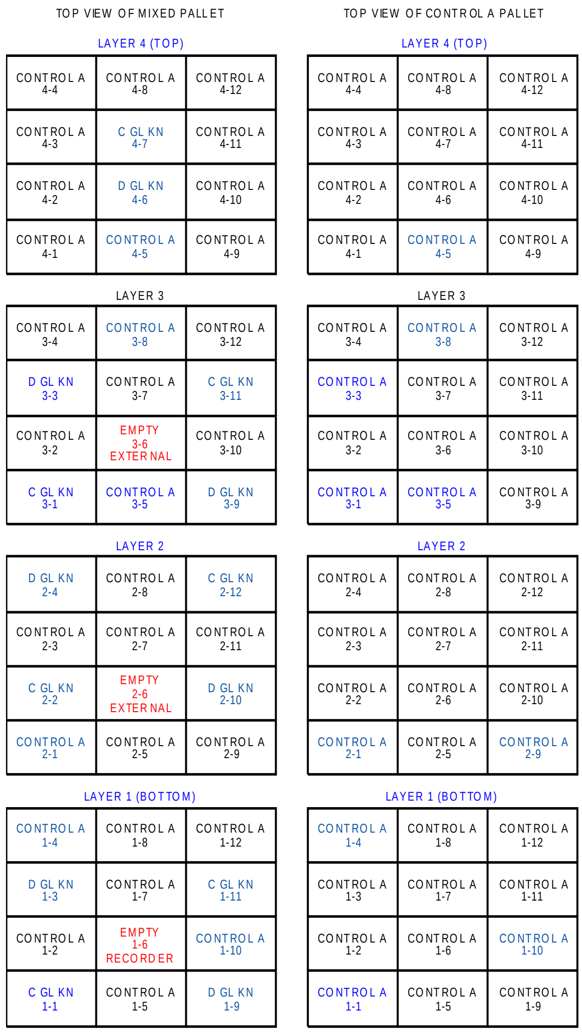

Figure 23. Locations of Inspected MRE Ration Cases, highlighted in blue, and the location of the SAVER 9X30 Field Data Recorder, highlighted in red.

The inspection plan is documented below:

1. Upon receipt of test containers, they were inspected for any signs of physical damage and reported findings
2. Selected seven cases from each pallet of each sample set of test samples and labeled accordingly
3. Removed SAVER 9X30 and associated external accelerometers from pallet
4. From each case VETCOM inspected four MRE rations and NSRDEC inspected the remaining eight MRE rations
5. VETCOM followed DSCP document 4155.2, App A for MRE ration inspection while NSRDEC engineers focused on the meal bag, retort and non-retort packaging
6. Failure rates were recorded for each sample set and pictures of representative failures were also documented, in addition representative failures were also kept

6.0 PERFORMANCE ASSESSMENT

6.1 DESIGN AND LAYOUT OF TECHNOLOGY COMPONENTS AND BASELINE DATA

The current and nanocomposite retort pouches are shown in Figure 24. Retort Pouch Structures A. Current Components B. Nanocomposite The pouch was then packed into a paperboard container and then inserted into the Meal Bag. The Penne Pasta was packaged in the current component retort pouch and the nanocomposite retort pouch.

A. Current Retort Pouch B. Nanocomposite Retort Pouch.

Figure 24. Retort Pouch Structures A. Current Components B. Nanocomposite

Figure 25 shows the production run and assembly line at AmeriQual during filling of the nanocomposite pouches with the penne pasta and then proceeding to the packing of the containers.

Figure 25. Filling of the Nanocomposite Retort Pouches

Figure 26 shows the non-retort pouch for both the current components and the nanocomposite pouch. The pretzels do use an oxygen scavenger sachet which was placed into each pouch.

A. Current Non-Retort Pouch

B. Nanocomposite Non-Retort Pouch

Figure 26. Non-Retort Pouches A. Current Component B. Nanocomposite

Figure 27 shows the non-retort film on AmeriQual's pouch forming machine line. This line was used to form the pouches and then pack the pretzels.

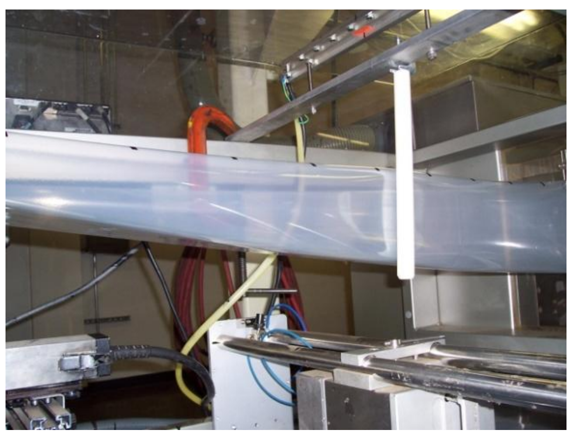

Figure 27. Nanocomposite Film for Non-Retort Pouch

Figure 28 shows the current component and nanocomposite Meal Bags. The Penne Pasta Menu # 14 contains the following: Penne Pasta, Pretzel, Seasoning Blend, Toaster Pastry, Beef Snack, French Vanilla and Mocha Cappuccino, Lemon Tea, Accessory C (4), Spoon, Ration Heater, and Hot Beverage.

A. **Current component Meal Bag** B. **Nanocomposite Meal Bag**

Figure 28. Meal Bags A. Current Component B. Nanocomposite

Figure 29 shows all the pallets of MREs that were generated for the demonstration and validation plan.

Figure 29. Pallets of MREs for ESTCP Program.

Baseline characterization included the evaluation of the penne pasta and the pretzels for end item inspection. The food in the MRE was prepared in accordance with the military specifications.[11;12] AmeriQual has prepared these menu items and performed the quality control inspections before and after filling and packing the pouches and MRE containers. All end item inspections were conducted and passed by AmeriQual for the current components and nanocomposite packaging.

Table 20 gives the identification and number of each Meal Bag and retort and non-retort pouches that were prepared. Seven hundred pouches were prepared to perform the demonstration tests at NSRDEC which were presented in Table 8.

Table 20. Identification and Quantity of Pouches and MRE Rations Filled and Packed at AmeriQual

	Nanocomposite Pouches		Current Technology Pouches	
Identification	Non-Retort Pretzels Nanocomposite	Retort Penne Pasta GL/K-N (A)	Non-Retort Current	Retort Current
A Current Technology	—	—	5000	5000
C Current 11 mil Meal bag	1152	1152	—	—
D Nanocomposite 6 mil meal bag	750	750	—	—
E Insect, Sensory and Storage Study	700	700	—	—
Total	2602	2602	5000	5000

Note in September, 2009 time frame, another production run consisting of 2500 each of the current component Meal Bag and the nanocomposite Meals Bags were produced. AmeriQual packed and assembled the MRE again as performed previously. Nanocomposite meal bags were made properly as a tube with no side seals. These were used for the rough handling and transportation/distribution study.

6.1.1 Baseline Data for the Barrier Properties

The oxygen barrier properties for the retort pouch were analyzed before and after the retort process and the oxygen transmission rate (OTR) values are below the MRE specification which is depicted in Figure 30. The experiments were performed with MOCON Oxtran according to standard methods.[13] In the case of high humidity at 90% before and after retort, the samples have exceptional barrier data. The negative values are shown as the OTR of these films approaches the lower permeability limit of the test equipment, which is 0.005 cc/m^2-day.

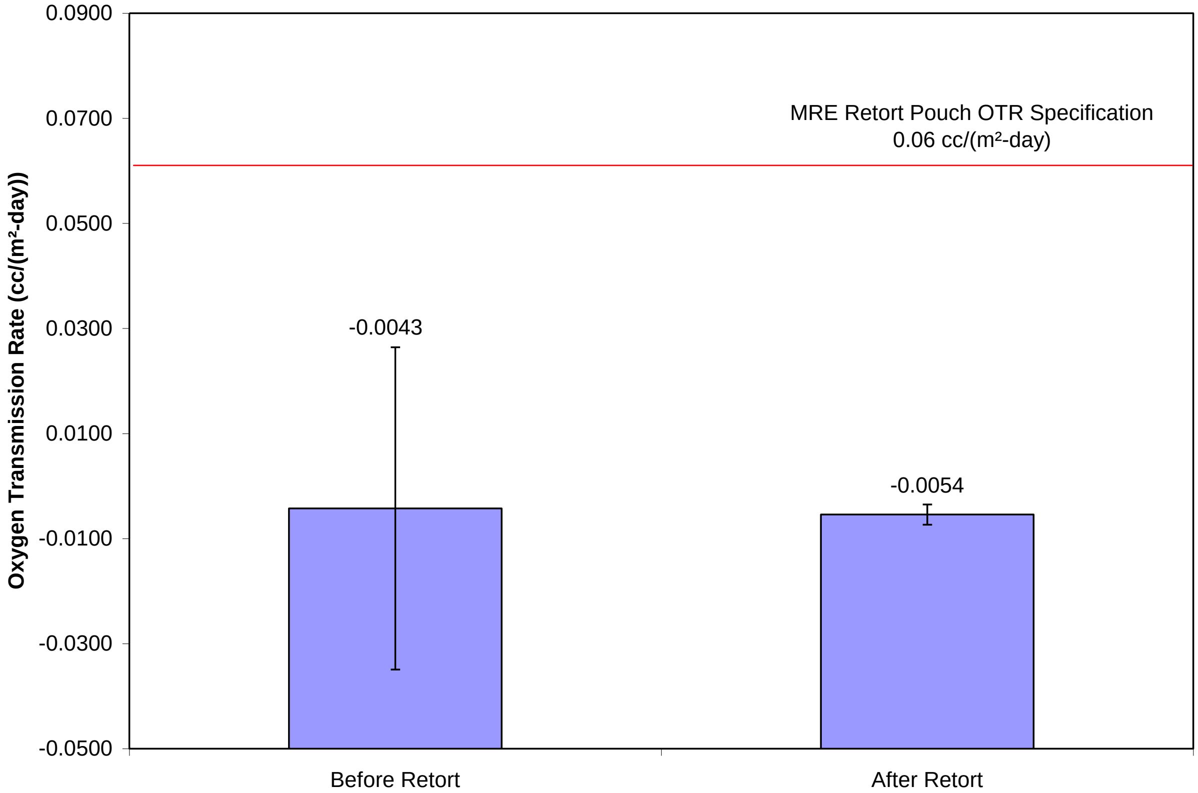

Figure 30. Oxygen Transmission Rate for Nanocomposite Retort Pouches

The samples were also evaluated by the standard methods for water vapor transmission properties.[14] As shown in Figure 31, , the water vapor transmission rate (WVTR) actually decreases after retort. All these values were acceptable rates especially since the Meal Bag provided a second layer of water vapor barrier.

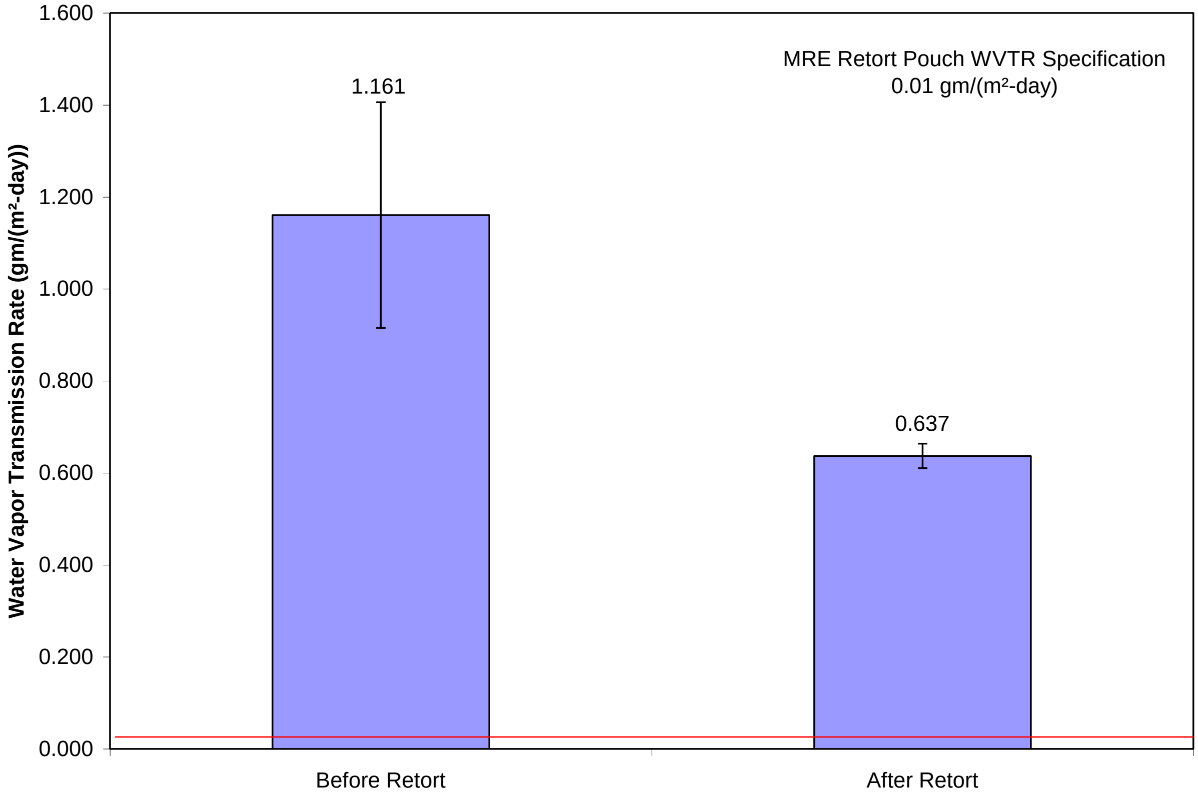

Figure 31. Water Vapor Transmission Rate of Retort Pouches

6.1.2 Baseline Characterization for Rough Handling

Preliminary testing was performed for the current components and the nanocomposite packaging for rough handling. The purpose of this preliminary study was to train our inspector for detecting failures and to observe where the defects and failures may occur. Considerable time was spent evaluating and studying the military documents along with the packaging to gauge the criteria. Three cases of each of the following were rough handled: current Meal Bag and 6 mil nanocomposite Meal Bags. The test samples were subjected to a one hour vibration test at 268 cycles / minute and a 10 drop test sequence at 21 inches with 72 hours of conditioning in between tests. The three cases of each prototype were tested at a high temperature environment (100°F) and a cold weather environment (-17°F). No visible damage, stress cracks, pinholes and tear were noted. The location of each defect was also recorded. Internal failure and peelable seal failures were also recorded for each bag. In general, the nanocomposite Meal Bags did worse than the current components especially at the lower temperature. This was again a small group of samples, and therefore not enough data was collected to conclude anything.

6.1.3 Baseline Characterization for the Altitude Testing

A hydrobaromic altitude test to determine how the packaging behaves as a function of altitude was performed.[15] Altitude testing was completed at the US Army Research Institute of Environmental Medicine (USARIEM) High Altitude Research Facilities. The current component and nanocomposite MRE Meal Bags (6 mil Neat and Nano and 11 mil Neat and Nano) were filled with MRE food pouches and 4 replicates of each were tested. Figure 32 illustrates the containers and individual Meal Bags at elevated altitude; the samples were arranged on tables in the chamber and the altitude was ramped up at a rate of 2,000 ft/min to 10,000 feet and then held at that altitude for 5 minutes. Then the altitude was ramped at 5,000 foot increments up to 35,000 feet and at every 5,000 foot increase the altitude was held for 5 minutes (i.e. ramp to 10,000 feet hold for 5 minutes, ramp to 15,000 feet hold for 5 minutes, etc). The altitude was ramped up to 35,000 feet in order to simulate the altitude of an aircraft that might transport the Meal Bags to the field. Again this experiment was used to obtain a baseline of where the failures might occur during operational testing. The inspector was trained to evaluate the failure at the side, peelable and manufactured seals.

Figure 32. Hydrobaromic Chamber with Meal Bags.

6.2 LABORATORY TEST RESULTS

6.2.1 Assure Shelf Stability with Microbial Testing

Microbiological tests were conducted throughout the storage study, at predetermined intervals, to determine the number of colonies of microorganism per gram, which is the metric for this objective. The data requirement is a test analyzing the aerobic plate count for yeast and mold colonies present in the retort pouch food product. The success criterion was met as there were less than 10 colonies per gram in the food sample for samples tested. Five samples were tested of each condition. The control and nanocomposite packaging behaved the same.

6.2.2 Water activity – Moisture Content

Table 21 displays the water activity and water content for the pretzels stored in the control and nanocomposite food pouches at 100°F. The control water activity was approximately .200 at 2, 4 and 6 months while the nanocomposite pouch decreased from .18 to .16 to .15 at 2, 4, and 6 months, respectively. The moisture content for both the control and nanocomposite pouch ranged from 4.4% at 2 months to 3.5% at 6 months and no significant differences when the error bar was considered.

Table 21. Water Activity and Moisture Content of the Control and Nanocomposite Non-Retort Pouch at 100°F

100°F	Water Activity				Moisture Content (% moisture)			
	Control Non-Retort		Nanocomposite		Control Non-Retort		Nanocomposite	
	Avg.	Std. Dev.	Avg.	Std. Dev.	Avg.	Std. Dev.	Avg.	Std. Dev.
2 months	0.2041	0.0006	0.1855	0.0057	4.484	0.100	4.381	0.066
4 months	0.2135	0.0047	0.1597	0.0064	4.326	0.182	3.945	0.100
6 months	0.2231	0.0010	0.1476	0.0021	3.962	0.170	3.528	0.346

Table 22Table 22 shows the water activity and moisture content for control and nanocomposite pouch at 120°F. The water activity values were consistently at a .2 value except for the control at 4 weeks. The moisture content was also consistent in a range of 4.7 to 5.2 with the nanocomposite pouch being closer to 5 for all three time periods of 2, 4 and 6 weeks.

Table 22. Water Activity and Moisture Content of the Control and Nanocomposite Non-Retort Pouch at 120°F

120°F	Water Activity				Moisture Content (% moisture)			
	Control Non-Retort		Nanocomposite		Control Non-Retort		Nanocomposite	
	Avg.	Std. Dev.	Avg.	Std. Dev.	Avg.	Std. Dev.	Avg.	Std. Dev.
2 weeks	0.2075	0.0029	0.2118	0.0053	4.707	0.019	5.257	0.074
3 weeks	0.2174	0.0032	0.1937	0.0026	4.869	0.099	5.086	0.444
4 weeks	0.1693	0.0044	0.2002	0.0060	5.267	0.865	4.952	0.118

Table **23** shows the water activity and moisture content for the pouches at 40°F. The results were all consistent for the controls for water activity with values in the .2 to .25 range. The nanocomposite pouch began with a higher water activity of .33 and increased to .44 at 12 months and was at a high of .53 at 30 and 36 months. The water barrier of this non-retort pouch was different than the retort pouch and this was evident at this storage temperature beginning at 12 months. Pretzels were undergoing some staling at the 40°F as was observed and was discussed in the sensory testing. The moisture content for the control ranged from 4.8 to 5.3% while the nanocomposite range varied from 6.0 to 8.9%. There was actually a decrease in value until 18 months and then increased at 36 months.

Table 23. Water Activity and Moisture Content of the Control and Nanocomposite Non-Retort Pouch at 40°F

40°F	Water Activity				Moisture Content (% moisture)			
	Control Non-Retort		Nanocomposite		Control Non-Retort		Nanocomposite	
	Avg.	Std. Dev.	Avg.	Std. Dev.	Avg.	Std. Dev.	Avg.	Std. Dev.
½ month	0.2260	0.0030	0.3328	0.0035	4.833	0.087	6.000	0.072
1 month	0.2081	0.0060	0.3658	0.0296	7.778	4.768	6.372	0.275
2 months	0.2148	0.0031	0.3535	0.0099	4.772	0.051	7.101	1.327
4 months	0.2221	0.0007	0.3979	0.0033	4.270	0.138	5.776	0.120
6 months	0.2295	0.0029	0.3973	0.0070	3.825	0.155	5.702	0.091
12 months	0.2224	0.0017	0.4482	0.0052	3.291	0.365	5.144	0.091
18 months	0.2523	0.0043	0.4613	0.0072	3.783	0.106	6.036	0.217
24 months	0.2282	0.0125	0.5418	0.1068	4.684	0.017	7.874	0.452
30 months	0.2305	0.0054	0.5375	0.0077	5.295	1.633	7.659	0.132
36 months	0.2160	0.0046	0.5353	0.0289	5.314	0.044	8.920	0.061

illustrates the water activity for the control pouch at 80°F to be consistent at approximately .22 for all time periods while the nanocomposite ranged from .29 at 6 months to .321 at 36 months. The moisture content increased from 2.8 at 6 months to 4.3 % for the control while nanocomposite values began at 4.7% and increasd to 6.4%.

Table 24. Water Activity and Moisture Content of the Control and Nanocomposite Non-Retort Pouch at 80°F

80°F	Water Activity				Moisture Content (% moisture)			
	Control Non Retort		Nanocomposite		Control Non-Retort		Nanocomposite	
	Avg.	Std. Dev.	Avg.	Std. Dev.	Avg.	Std. Dev.	Avg.	Std. Dev.
6 months	0.2273	0.0037	0.2976	0.0018	3.838	0.081	4.834	0.061
12 months	0.2192	0.0054	0.3295	0.0087	3.063	0.155	4.498	0.152
18 months	0.2542	0.0047	0.3066	0.0063	3.660	0.093	5.044	0.770
24 months	0.2144	0.0031	0.3003	0.0034	4.579	0.156	5.547	0.112
30 months	0.2296	0.0085	0.2160	0.0008	4.247	0.111	5.099	0.191
36 months	0.2123	0.0032	0.3210	0.0040	4.350	0.018	6.400	0.011

6.2.3 Lipid Oxidation

The complete set of chromatograms and raw data can be found in the appendix. All samples measured a hexanal abundance level less than 1ppm (documented threshold for sensory recognition).

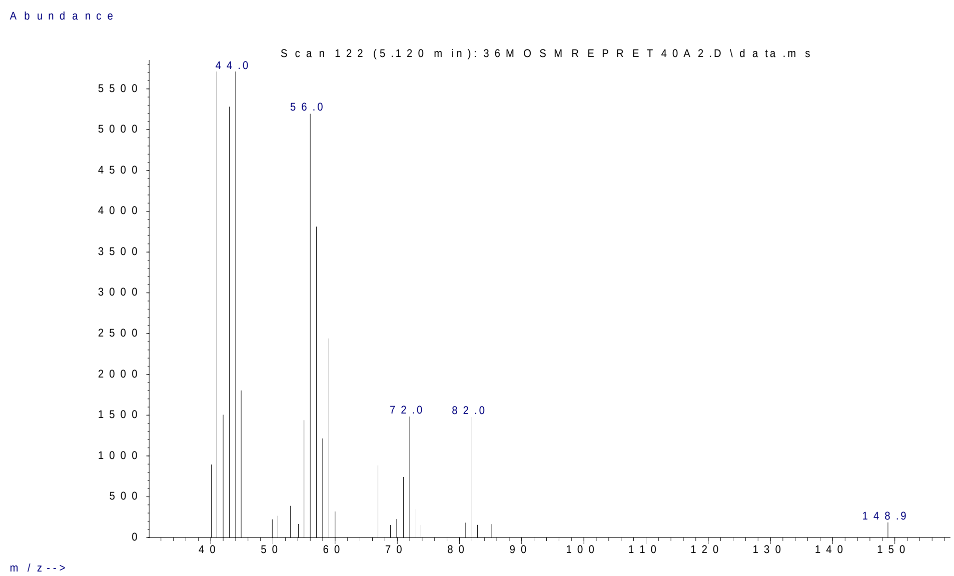

Figure 33. A Spectrum of the Hexanal Peak from the 36 Month Pull (Pretzel:MRE) Confirming the Presence of Hexanal.

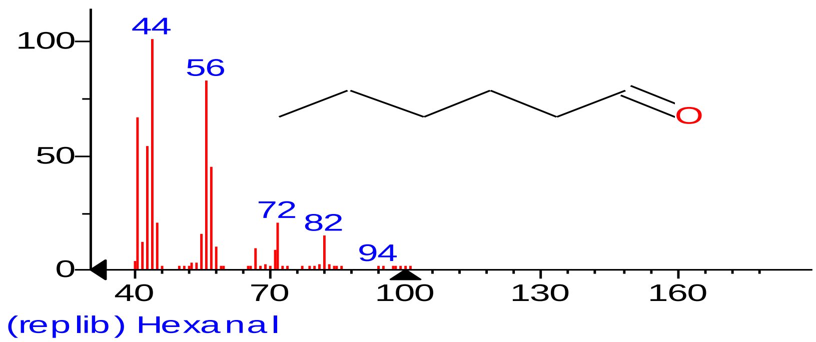

Figure 34. The Mass Spectrum of Hexanal Found in the Mass Spectrum Library is the Same as the Sample Spectrum of Hexanal.

Table 25. Hexanal Abundance in Non-Retort Pouches

Hexanal Measured in Abundance in Pretzels							
Hexanal standard			34371883 (1ppm)				
	Control			Average	Nano		Average
40F							
Time 0	0	0	0	0	0	0	0	0*
2 weeks	0	0	0	0	0	0	0	0*
3 weeks	0	0	0	0	0	0	0	0*
4 weeks	trace	trace	1986497	1986497	1546987	1215634	3198930	1987184
2 months	0	0	0	0	0	0	0	0*
4 months	0	0	0	0	0	0	0	0*
6 months	1523648	1752436	963524	1413203	2031568	1925426	1425638	1794211
12 months	0	0	0	0	0	0	0	0*
18 months	2151155	2147284	2152452	2150297	2151369	2153008	2147343	2150573
24 months	2064584	2594130	1984625	2214446	2268943	2059487	2384975	2237802
36 months	2215436	2012584	2053687	2093902	***	***	***	***
80F								
Time 0	0	0	0	0	0	0	0	0*
6 months	0	0	0	0	0	0	0	0*
12 months	0	0	0	0	0	0	0	0*
18 months	4133736	4503325	4407073	4348045	3582031	4565871	4849536	4332479
24 months	3951284	3846527	4287619	4028477	4168235	3984768	4025864	4059622
36 months	3625849	3258479	4158964	3681097	***	***	***	***
100F								
Time 0	0	0	0	0	0	0	0	0*
2 months	0	0	0	0	0	0	0	0*
4 months	0	0	0	0	0	0	0	0*
6 months	2546138	2365241	2698547	2536642	1564896	1532468	1742136	1613167
120F								
Time 0	0	0	0	0	0	0	0	0*
2 weeks	0	0	0	0	0	0	0	0*
3 weeks	0	0	0	0	0	0	0	0*
4 weeks	2883606	11762905**	2736187	2809897	2246031	2209367	1991700	2149033

*All samples had a trace of hexanal that was found. It was not quantified because it was so low.

** Not indicative of hexanal presence. It is believed that this was a compromised package

***Hexanal was unable to be quantified due to co-elution. However, it is well below the threshold amount.

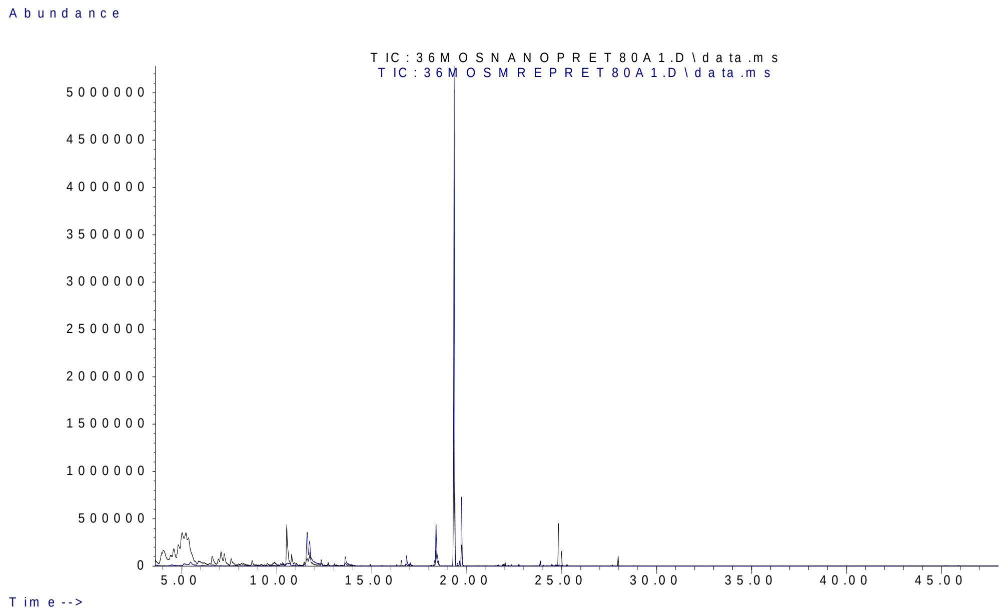

Figure 35. Overlay of the Chromatogram of Control and Nanocomposite Non-Retort Pouch

The overlaid chromatograms of the pretzels stored at 80°C. The chromatograms are very similar except for the co-elution of compounds at 5 minutes. Due to this co-elution, hexanal could not be quantified, but it is less than the sensory threshold.

The aldehyde, hexanal, was monitored throughout the duration of the storage study to measure the level of lipid oxidation that occurred in the penne samples just as was done for the pretzel samples. The same procedure was followed as outlined in section.
Below is Figure 36 a spectrum of the hexanal peak from the penne at 26 month time interval.

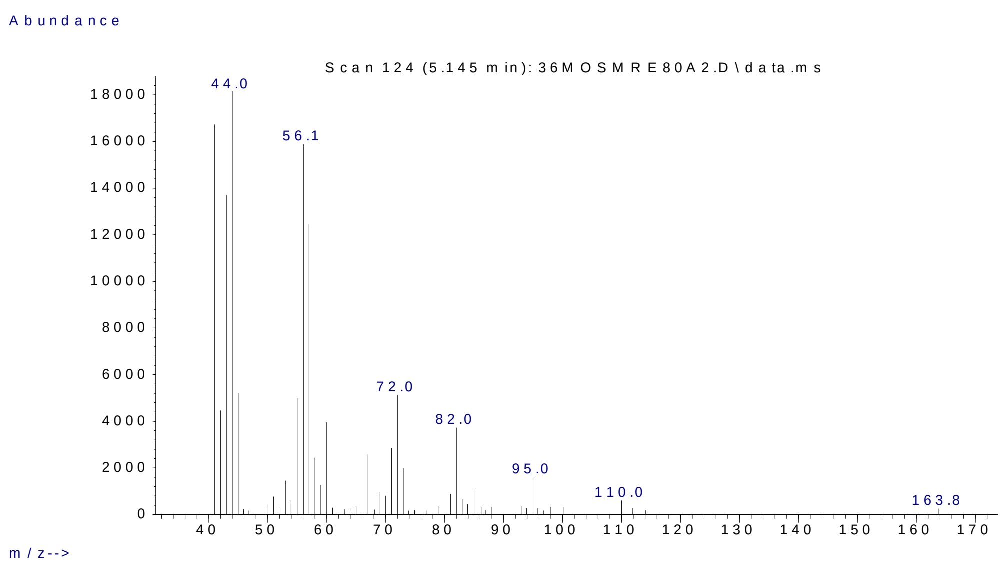

Figure 36. A Spectrum of the Hexanal Peak from the 36 Month Pull (Penne: Retort/Control) Confirming the Presence of Hexanal.

Table 26. Hexanal Abundance / Lipid Oxidation in Retort Pouches

Hexanal standard 34371883 (1ppm)

	Control			Average	GLKN			Average
40F								
Time 0	0	0	0	0*	0	0	0	0*
2 weeks	0	0	0	0*	0	0	0	0*
3 weeks	0	0	0	0*	0	0	0	0*
4 weeks	2884084	3871769	4297779	3684544	6178495	3933297	3978017	4696603
2 months	0	0	0	0*	0	0	0	0*
4 months	0	0	0	0*	0	0	0	0*
6 months	3251689	3541588	3412576	3401951	4531286	5945236	6235874	5570799
12 months	0	0	0	0*	0	0	0	0*
18 months	4963882	4521638	4125168	4536896	8464092	8854236	8014728	8444352
24 months	4569823	4482571	5067825	4706740	8065975	8345698	7654823	8022165
36 months	4685217	4236597	4528613	4483476	7965238	7842519	7952418	7920058
80F								
Time 0	0	0	0	0*	0	0	0	0*
6 months	0	0	0	0*	0	0	0	0*
12 months	0	0	0	0*	0	0	0	0*
18 months	12724488	12773404	10006040	11834644	NA	10619045	8945747	9782396
24 months	10546872	11578496	10985476	11036948	9984652	11564284	10025368	10524768
36 months	9851247	10254983	10025486	10043905	9562487	10251386	9254128	9689334
100F								
Time 0	0	0	0	0*	0	0	0	0*
2 months	0	0	0	0*	0	0	0	0*
4 months	0	0	0	0*	0	0	0	0*
6 months	5620479	6029306	3971655	5207147	4775771	7357434	11816509	7983238
120F								
Time 0	0	0	0	0*	0	0	0	0*
2 weeks	0	0	0	0*	0	0	0	0*
3 weeks	0	0	0	0*	0	0	0	0*
4 weeks	trace	3152034	3316832	3234433	3685261	3748308	3229310	3554293

*All samples had a trace of hexanal that was found. It was not quantified because it was so low. The abundance of hexanal is under the sensory threshold for all samples.

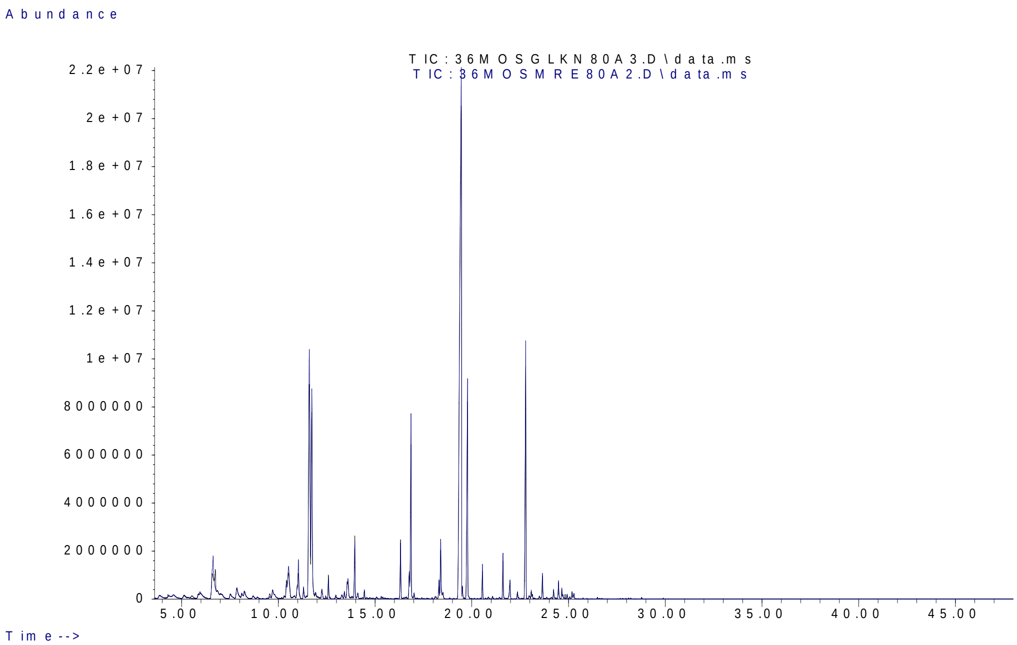

Figure 37. Overlay of the Control and Nanocomposite Retort Pouch

Figure 37 shows a chromatogram overlay of the GLKN (black) and MRE (blue) samples stored at 80 for 36 months. The 2 chromatograms are relatively identical.

Hexanal abundance is below the sensory threshold and there was almost no difference between the different penne control and nanocomposite samples. The same chemistry is happening in all samples and the chromatograms overlay with each other from the different packaging

6.2.4 Maintain Integrity of Pouch

This objective is assuring that the non-retort pouch performs according to the specification ACR-M-029 and MIL-PRF-44073. The metric was percentage of retort pouches that do not rupture or burst. The data requirement was internal pressure testing using a Lippke 2500 SL. The success criterion was that greater than 90% of the non-retort pouches exhibit no rupture or seal separation greater than 1/16 of an inch.
Internal pressure testing using a Lippke 2500 SL was performed for 8 samples at each storage pull temperature and time. The success criteria was met as there was 100% of the non-retort pouches exhibit no rupture or seal separation greater than 1/16 of an inch.

6.2.4.1 Maintain Meal Bag Integrity with Ease of Opening (Top Seal) and (Bottom Seal)

The seal strength test, ASTM F88-07a, was performed with 10 samples as this was chosen to permit adequate representation of performance. This was based on the amount that AmeriQual used in their end item testing, but also ASTM F88-07a provides a complete inter laboratory study where experiments were performed with 10 or 30 samples. The results concluded that using 30 samples did not show significant variation in the data. The data analysis included the calculations of mean, range and standard deviation. The success criterion is that greater than

90% of the average seal strengths are greater than 4 lb/in but less than 10 lb/in. Seal Strength Test was done using the Instron® 4400R, 500 N Load Cell, 10 in/min (25.4 cm/min) testing speed, 2 inch (5.08 cm) gauge length. Utilized to find force needed to peel the preformed seal apart. Both the top and bottom seal meet the success criteria as shown in Table 27. The peel strength was tested on the Meal Bag's preformed seal. This is the seal that is intended to be peeled apart when opening the bag. Although the preformed seal has a chevron, the samples were taken from the flat sections of the seal. The results are consistent and show no clear top or bottom performer. The variations that are present can be a result of the material blend as well as seal parameters (ex. sealing temperature and dwell time time).

The top seal is the peelable manufactured seal and this was evaluated at NSRDEC with the Instron machine while the bottom seal is evaluated at AmeriQual after the food contents have been assembled into the Meal Bag.

Table 27. Seal Strength for the Meal Bag

Seal Strength* (lbf/in)	Control Meal Bag	Nanocomposite Meal Bag
Top Seal	6.62 ± .515	4.82 ± .371
Bottom Seal	8.02 ± .523	6.42 ± .757

*18 Samples Tested

Testing conducted at NSRDEC on the top seal strengths using 18 samples is shown in the Appendix B.

6.2.5 Maintain Low Oxygen Concentration for Shelf Life Requirements

Oxygen concentration was at 0 ppm for the control and non-retort nanocomposite packaging during the entire storage study at all temperatures and time periods. AmeriQual generated this data using 8 samples per pull. As shown in Table 28 and Table 29, all samples passed the requirement.

Table 28. Oxygen Concentration Accelerated Storage Study

Time	120°F	100°F
0	Passed	Passed
2 weeks	Passed	Passed
3 weeks	Passed	Passed
4 weeks	Passed	Passed
2 months	-	Passed
3 months	-	Passed
4 months	-	Passed
5 months	-	Passed
6 months	-	Passed

Table 29. Oxygen Concentration Long Term Storage Study

Time (months)	40 °F	80 °F	100 °F
0	Passed	Passed	Passed
6	Passed	Passed	Passed
12	Passed	Passed	Passed
18	Passed	Passed	Passed
24	Passed	Passed	Passed
30	Passed	Passed	Passed
36	Passed	Passed	Passed

6.2.6 Sensory Results

Most notable results demonstrate a large negative impact of “Non-retort Nano” treatment on pretzels stored 30 months at 40^o F and at other time/temperature combinations. The texture of these pretzels were noted for being stale and soft/non-crunchy (the normal attribute is ‘crunchy’ for this product). There are less notable but significant differences in some of the other comparisons. For example: (a) Pretzels at 30 months, the ‘Odor’ quality of 80^o F ‘Non-retort MRE’ vs. ‘80^o F ‘Non-retort Nano’ (b) Penne pasta at 30 months, the ‘Appearance’ quality of 40^o F ‘Retort GL/K-N’ vs. 40^o F ‘Retort MRE. For tech panels, overall quality ratings were combined (time & temperature categories) by film materials. This revealed small but significant differences for: (a) Pretzels ‘Non-retort MRE’ vs. ‘Non-retort Nano’ but not for (c) Penne pasta ‘Retort GL/K-N nano’ vs. ‘Retort MRE. Some comparisons had no significant differences. Timeline graphs illustrate a general similarity congruency across the various intervals except in the case of the previously mentioned Pretzels stored at 40^o F.

<u>Non-retort Nano vs. Non-retort MRE</u>—It appears that pretzels stored at cooler temperatures are more detrimental by the use of ‘Non-retort Nano’ packaging. This substitution cannot be recommended based on these results. A separation of quality ratings over time is evident as well. This further underscores a negative recommendation for the non-retort nano packaging material.
<u>Retort GL/K-N nano vs. Retort MRE</u>—It appears that the small difference of ratings for ‘appearance’ quality at 30 months 40^o F is a significant difference that could lead to other significant differences and result in a negative recommendation. However, it does not have any significant differences in the overall conglomeration of data and presently has a guarded recommendation. The 36-month evaluation could change that if the timeline trends in quality widen.

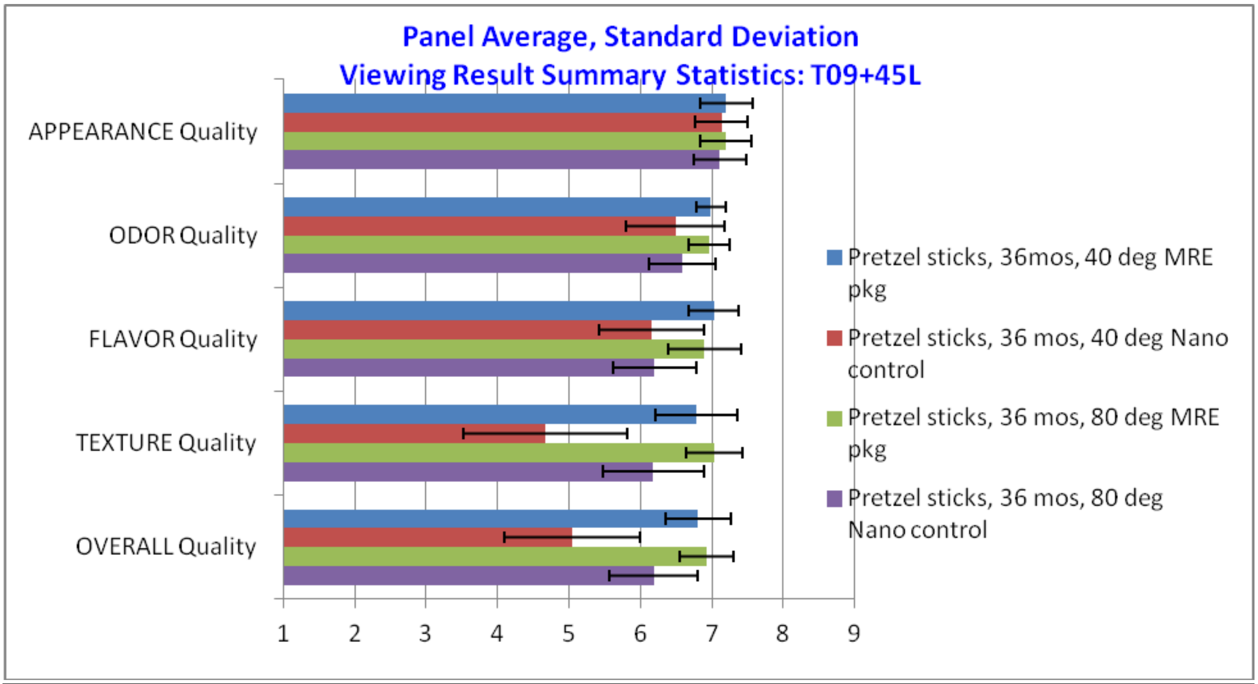

Figure 38. Panel Average for Non-Retort Pouch After 36 Months Storage at 40 and 80°F.

Table 30. Summary of Means for Non-Retort Pouch after 36 Months Storage at 40 and 80°F – Duncan's.

Summary of Mean-Scores, P-Values, and Significance (Duncan's) Test Result Code - T09+45L						
This test was performed on 10 panelists.						
Attribute	Pretzel sticks, 36mos, 40 deg MRE pkg	Pretzel sticks, 36 mos, 40 deg Nano control	Pretzel sticks, 36 mos, 80 deg MRE pkg	Pretzel sticks, 36 mos, 80 deg Nano control	P-Value	Sig
APPEARANCE Quality	7.2	7.14	7.19	7.11	0.6452	NS
ODOR Quality	a 6.99	b 6.49	a 6.96	ab 6.59	0.0335	*
FLAVOR Quality	a 7.03	b 6.16	a 6.9	b 6.2	0.0005	***
TEXTURE Quality	ab 6.79	c 4.67	a 7.04	b 6.18	0.0001	***
OVERALL Quality	a 6.81	c 5.05	a 6.93	b 6.19	0.0001	***

*=.05
**=.01
***=.001

Table 31 . Summary of Means for Non-Retort Pouch after 36 Months Storage at 40 and 80oF (Tukey's HSD)

Summary of Mean-Scores, P-Values, and Significance (Tukey's HSD) Test Result Code - T09+45L						
This test was performed on 10 panelists.						
Attribute	Pretzel sticks, 36mos, 40 deg MRE pkg	Pretzel sticks, 36 mos, 40 deg Nano control	Pretzel sticks, 36 mos, 80 deg MRE pkg	Pretzel sticks, 36 mos, 80 deg Nano control	P-Value	Sig
APPEARANCE Quality	7.2	7.14	7.19	7.11	0.6452	NS
ODOR Quality	a 6.99	a 6.49	a 6.96	a 6.59	0.0335	*
FLAVOR Quality	a 7.03	b 6.16	a 6.9	b 6.2	0.0005	***
TEXTURE Quality	ab 6.79	c 4.67	a 7.04	b 6.18	0.0001	***
OVERALL Quality	ab 6.81	c 5.05	a 6.93	b 6.19	0.0001	***

Table 32. Non-Retortable Packaging (MRE Control vs. Nano)

All "Liking/Disliking" data by treatment combined (40^{o} & 80^{o} F)—Pretzel MRE Non-retort vs. Nano Non-retort

Analysis of variance

Source	DF	Sum of squares	Mean squares	F	Pr > F
Model	1	70017.903	70017.903	49.470	< 0.0001
Error	234	331193.483	1415.357		
Corrected Total	235	401211.385			

Computed against model Y=Mean(Y)

Table 33. Comparison With a Control

Package type / Dunnett (two sided) / Analysis of the differences between categories and the control category Package type-Non-retort MRE with a confidence interval of 95%:

Category	Difference	Standardized difference	Critical value	Critical difference	Pr > Diff	Significant
Non-retort MRE vs Non-retort Nano	34.449	7.034	1.970	9.650	0.000	Yes

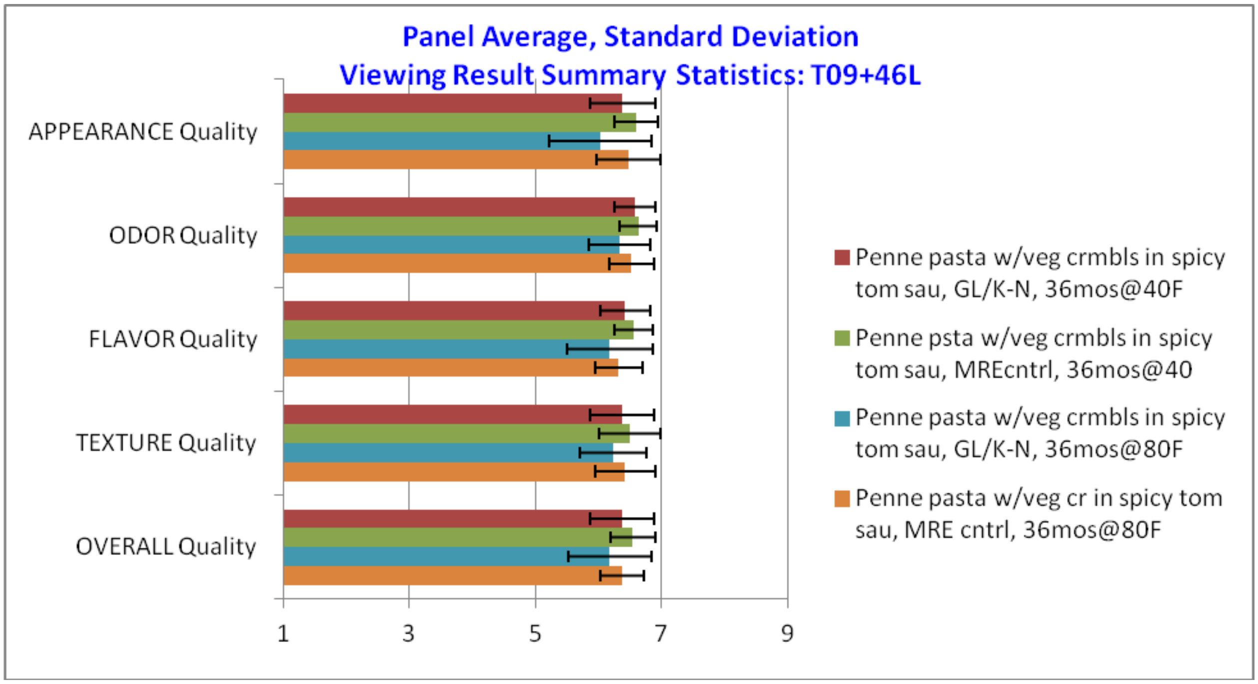

Figure 39. Tech Panel Evaluations 36 months Retort Pouches

Table 34. Summary of Mean Scores for 36 Months Storage Retort and Nano Retort Pouches (Duncan)

Summary of Mean-Scores, P-Values, and Significance (Duncan's) Test Result Code - T09+46L						
This test was performed on 12 panelists.						
Attribute	Penne pasta w/veg crmbls in spicy tom sau, GL/K-N, 36mos@40F	Penne pasta w/veg crumbs in spicy tom sauce, MRE control, 36mos@40	Penne pasta w/veg crumbs in spicy tom sauce, GL/K-N, 36mos@80F	Penne pasta w/veg in spicy tom sauce, MRE control, 36mos@80F	P-Value	Sig
APPEARANCE Quality	ab 6.38	a 6.59	bc 6.03	ab 6.48	0.0023	**
ODOR Quality	ab 6.57	a 6.63	b 6.33	ab 6.52	0.0001	***
FLAVOR Quality	a 6.42	a 6.55	ab 6.17	ab 6.33	0.022	*
TEXTURE Quality	6.37	6.49	6.23	6.42	0.0906	NS
OVERALL Quality	a 6.37	a 6.54	ab 6.17	a 6.37	0.0093	**

*=.05

**=.01

***=.001

Table 35. Summary of Mean Scores for Retort and Nano Retort Pouches (Tukey)

Summary of Mean-Scores, P-Values, and Significance (Tukey's HSD) Test Result Code - T09+46L						
This test was performed on 12 panelists.						
Attribute	Penne pasta w/veg crumbs in spicy tom sauce, GL/K-N, 36mos@40F	Penne pasta w/veg crumbs in spicy tom sauce, MRE control, 36mos@40	Penne pasta w/veg crumbs in spicy tom sauce, GL/K-N, 36mos@80F	Penne pasta w/veg in spicy tom sauce, MRE control, 36mos@80F	P-Value	Sig
APPEARANCE Quality	ab 6.38	a 6.59	ab 6.03	a 6.48	0.0023	**
ODOR Quality	a 6.57	a 6.63	a 6.33	a 6.52	0.0001	***
FLAVOR Quality	ab 6.42	a 6.55	ab 6.17	ab 6.33	0.022	*
TEXTURE Quality	6.37	6.49	6.23	6.42	0.0906	NS
OVERALL Quality	ab 6.37	a 6.54	ab 6.17	ab 6.37	0.0093	**

6.2.8 Assure Recyclability of Meal Bag

The Control Meal Bag had a melt temperature of 126.5°C ± .20 and the Nanocomposite Meal Bag was 118.9°C ± .15 which lies in the range for success criteria.

Table 36. Recycling Thermal Data for Meal Bag

Sample Test Conditions and Compositions	
Control Meal Bag	**Nanocomposite Meal Bag**
Barrel Profile: 190, 195, 200°C	Barrel Profile: 190, 195, 200°C
LDPE/Regrind from Meal Bag	LDPE/Regrind from Meal Bag
100/0	100/0
80/20	80/20
60/40	50/50
40/60	20/80
20/80	0/100
0/100	

MRE Control Meal Bags and the Nanocomposite Meal Bags were able to be processed at all percent weight compositions. The films processed better at the higher compositions of pure virgin LDPE rather than the regrind. Regrind material has already been processed and this may have had some lowering of the molecular weight which can diminish mechanical properties.

6.2.8.1 TREX Company Results

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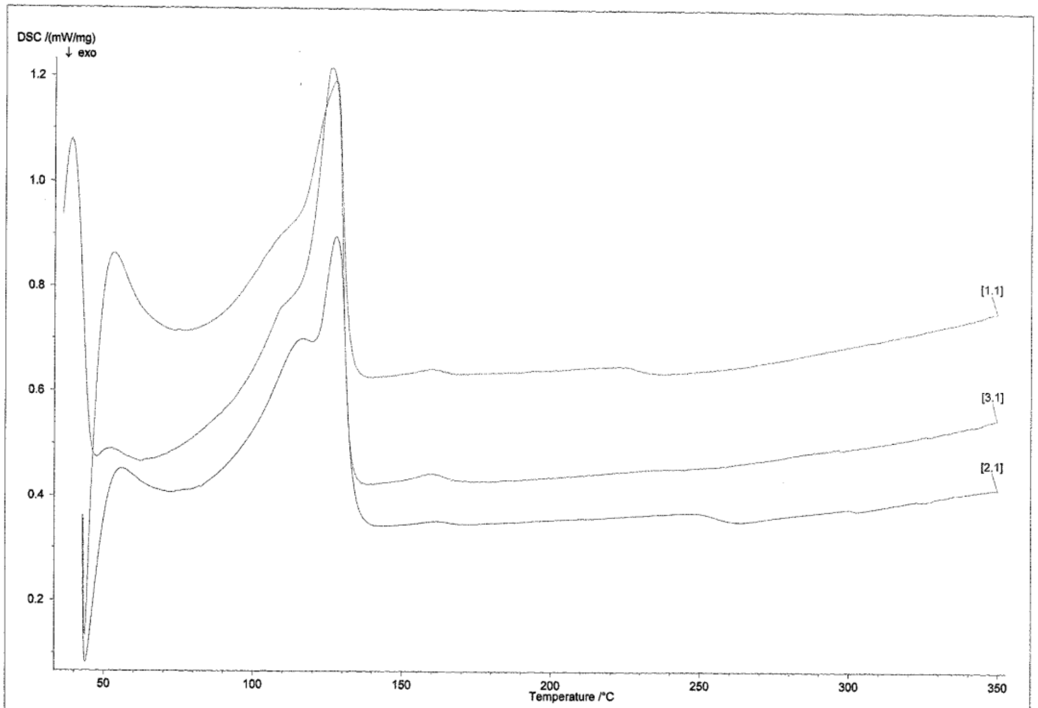
6.2.8.1.1 DSC Testing

DSC testing was performed to evaluate the melting characteristics of the polymer. The data is also useful in determining processing suitability in the TREX process. Melt peak (melting point) was 126°C with an onset temp of 117°C. These are typical values for most LDPE/LLDPE film encountered in the recycled PE stream at TREX.

The Control Meal Bag data showed several materials of equal parts ranging in melt points from 108◦C to 125◦C. Onset temperature occurred sooner than the typical TREX recycling material, but still within an acceptable range.

The Nanocomposite Meal Bag displayed a DSC curve that represents a single layer of film with a more homogenous composition (single peak as opposed to multiple peaks). The melt point was 116°C (probably LDPE) as opposed to the Control that contained some LLDPE judging by the melt peaks. The onset was much closer to the peak temperature also indicating one polymer type in the sample.

Comparison of the DSC data from both the Control sample and Nano sample at 25% inclusion with recycled PE and the typical 100% recycled PE is shown in Figure 40. There was no appreciable difference in melt peak and onset temperature when the samples were blended at this level.



[#] Instrument	File	Identity	Sample	Date	Mass	Segment	Range	Atmosphere	Correction
[1.1] NETZSCH DSC 204	25%- mri-nano.sdd	04	75% repro added	6/4/2012 10:40:02 AM	8.000 mg	1/2	40 °C/10.0(K/min)/350 °C	Nitrogen/20 / ---/---	000
[2.1] NETZSCH DSC 204	75%-repro-25% mri-c....	15	test 2	6/12/2012 1:54:16 PM	19.000 mg	1/2	40 °C/10.0(K/min)/350 °C	Nitrogen/20 / ---/---	000
[3.1] NETZSCH DSC 204	lear -repro.sdd	03	material for mir test	6/4/2012 9:27:44 AM	8.000 mg	1/2	40 °C/10.0(K/min)/350 °C	Nitrogen/20 / ---/---	000

Figure 40. DSC Comparison of 25% Inclusion to 100% Recycled PE

6.2.8.1.2 Melt Flow Testing and Rheometer Testing

Melt flow testing was evaluated using the Melt Flow Index. No significant differences were observed in all samples.

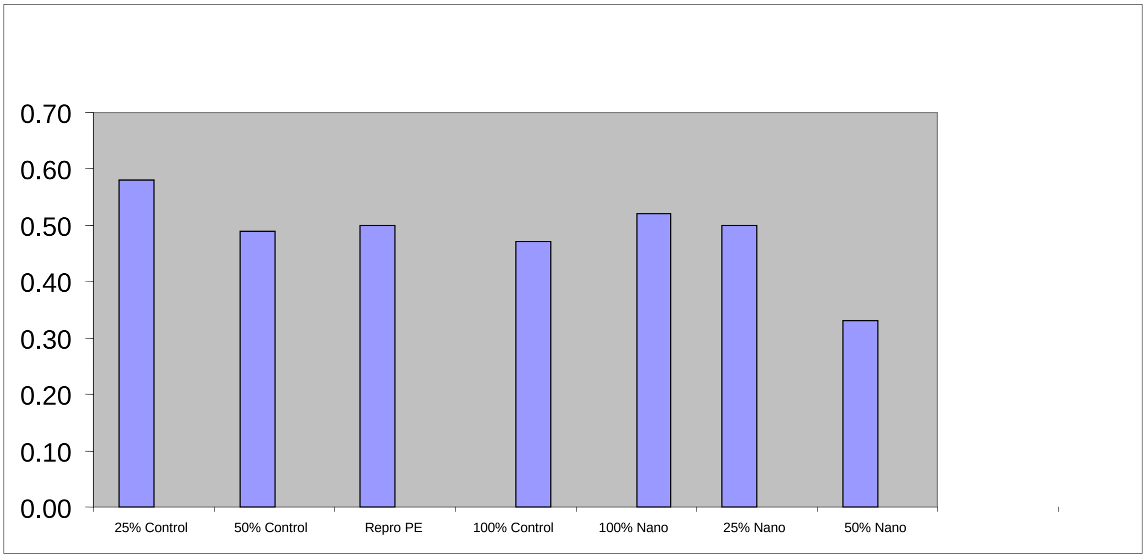


Figure 41. Melt Flow Index Data for Meal Bag.

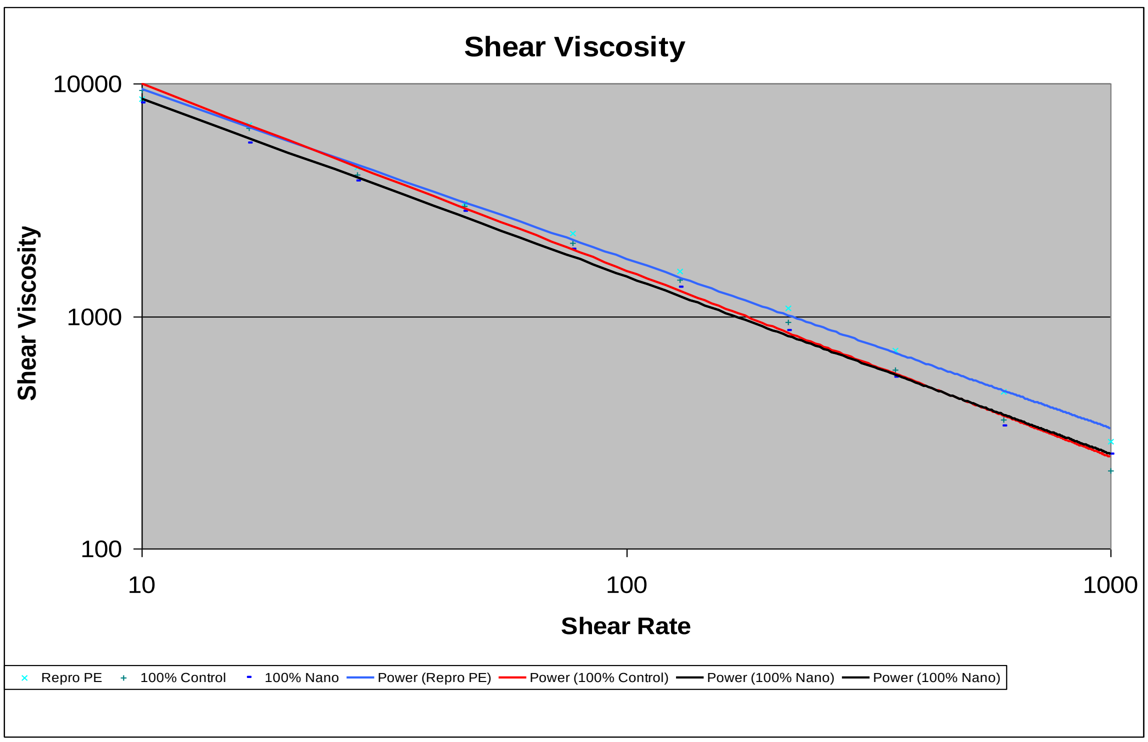


Figure 42. Rheometer Data on 100% Control and 100% Nano Samples.

Figure 42 indicates that both the Control sample and the Nano sample showed lower viscosity under shear than typical reprocessed recycled PE. However, when blended at 25% inclusion with recycled PE, the viscosity comes in line with typical PE values.

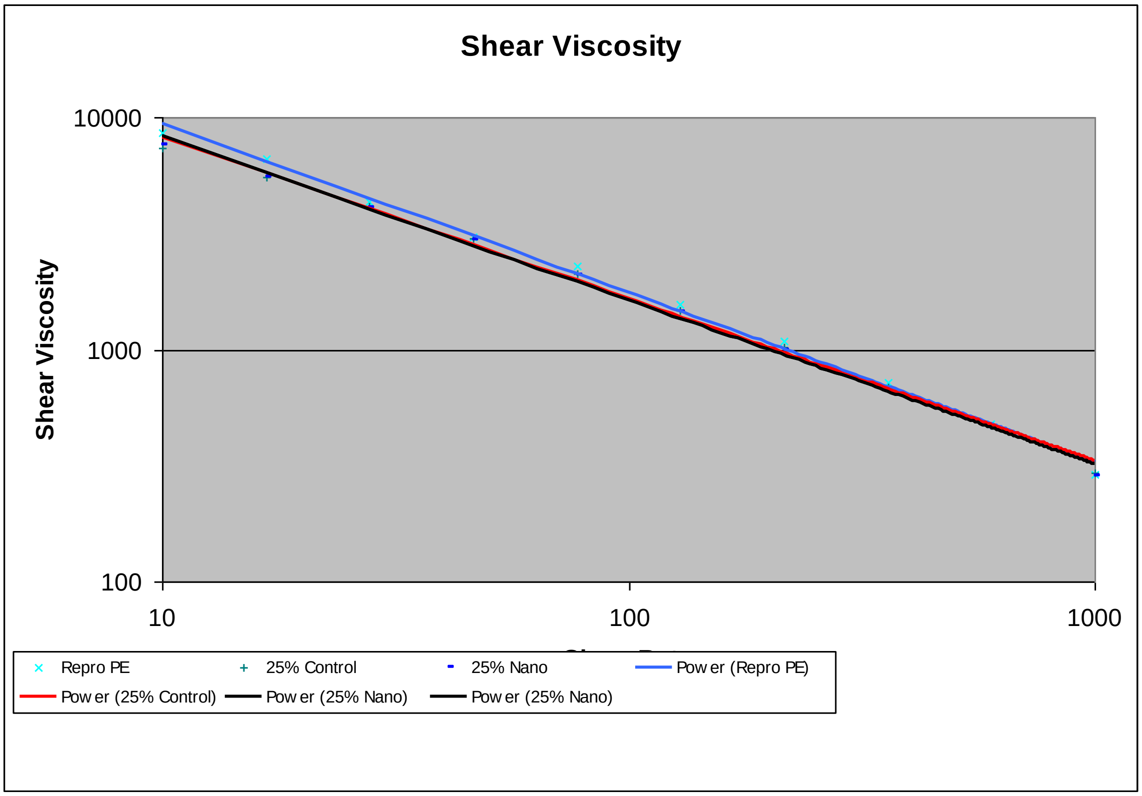


Figure . Rheometer Data at 25% Inclusion with Recycled PE.

The samples were additionally tested for color and ash content. The color data is included in Table 37 along with ash values.

Table 37. Color Data for the Control and Nano Meal Bag with Reprocessed PE.

Sample	L*	A*	B*	Ash %
Reprocessed PE	43.12	-1.5	3.45	1.85%
100% Control	53.21	7.82	12.74	3.68%
25% Control	49.05	3.24	8.52	
50% Control	52.19	5.47	10.69	
100% Nano	54.07	7.95	12.94	5.21%
25% Nano	50.39	3.5	8.14	
50% Nano	53.26	6.08	10.77	

This data shows that both the Control and Nano samples are highly pigmented and significantly shift the color values of the recycled PE.

6.2.8.1.3 Quantitative Statement from TREX

Based on these findings, both the control meal bag and the nanocomposite meal bag would be suitable for TREX recycled PE stream at 25% inclusion rates based on polymer rheology. The amount of pigment and color loading would limit the inclusion to certain TREX products based on color specs. There does not appear to be a significant processing advantage to either the Control sample or Nano sample.

6.2.8.1.4 Assure recyclability of non-retort pouch
6.2.6.1.4.1 Quantitative
The non-retort pouch was analyzed at NSRDEC and TREX by DSC. The pouch had the following melt transitions: 85% polyolefin at 132.7C, 10% PP at 184.1°C and 5% of PET at 254.5°C. Since these values range over 220°C, it would be difficult to recycle on commercial film recycling machinery. However, at NSRDEC the same type of recycling experiments for the Meal Bag were performed as shown in Table 38.

Table 38. Non-Retort Regrind Reprocessing Conditions

Barrel Profile: 290, 295, 300°C
LDPE/Regrind
100/0
80/20
50/50
20/80
0/100

The Non-Retort pouch could not process at pure regrind and barely processed at 80% regrind. There were some holes in the film. The film processed at the 50/50, 80/20 compositions were of better quality.

6.2.6.1.4.2 Qualitative
TREX analyzed the pouches and determined that they could not be recycled with the type of machinery due the mix of plastics. TREX has one of the most state-of-the art machinery for recycling; therefore, if they could be recycled at their facility, the chances of recycling at another facility would not be likely.

6.2.6.1.5 Assure Recyclability with Industry
As mentioned in the 6.2.8.01, TREX evaluated these materials and they are not considered recyclable due to the wide range of melting temperatures.

6.2.6.1.5 Assure Recyclability of Retort Pouch

The retort pouch was analyzed at NSRDEC and TREX by DSC . The pouch had the following melt transitions: 70% PP at 166.9°C, 20% Nylon at 223.7°C and 10% of PET at 255.1°C. Since these values range over 100°C, it would be difficult to recycle on commercial film recycling machinery. However, at NSRDEC the same type of recycling experiments for the Meal Bag were performed as shown in Table 39.

Table 39. Retort Regrind Reprocessing Conditions

Barrel Profile: 250, 255, 260°C
LDPE/Regrind
100/0
80/20
50/50

All the films processed better at the higher compositions of LDPE rather than the regrind. When compounding two different polymers, many things can affect their compatibility to reprocess together. The two polymers can differ in degradation temperature when being compounded and if one polymer degrades during reprocessing, the film was not processed successfully. Another factor is shear degradation, which affects the lengths of the polymer chains within the polymer. When reprocessed, you can break the polymer chains causing chain scission and this breaking of chains would alter the properties of the polymer possibly resulting in poor reprocessing.

For most of the regrind samples, trying to recycle at 100% regrind was not possible. However, it was possible to recycle portions of the material which would ultimately reduce waste and allow reprocessing of the waste for reuse.
The Retort pouch could not process at pure regrind and barely processed at 80% regrind. There were some holes in the film. The film processed at the 50/50, 80/20 compositions were of better quality.

6.2.6.1.5 .1 Qualitative

TREX analyzed the pouches and determined that they could not be recycled with the type of machinery due the mix of plastics. TREX has one of the most state-of-the art machinery for recycling; therefore, if they could be recycled at their facility, the chances of recycling at another facility would not be likely.

6.2.9 Insect Infestation Results

Ninety novel film pouches were used during this study. All pouches were exposed to 1,000 individuals for each of the following species: Red flour beetle, Sawtoothed grain beetle, Indianmeal moth, Cigarette beetle, and Warehouse beetle. Once the insects were released on day one, insect rearing media was added to the chamber to support life for the duration of the study. Study conditions were 80°±5° F and 60±5% relative humidity. Testing duration was 12 weeks with 30 pouches beingremoved at 4, 8 and 12 weeks.

All pouches were inspected for chew damage by submerging the pouch under water and checking for air leaks. Table 40 displays all the data for the non-retort pouch. There were no failures. Table 43 displays all the data for the retort pouch. There were no failures.

Table 40. Non-Retort Nanocomposite Pouch Insect Infestation Results

4 Week Non-Retort Nano Pouch			8 WeekNon-retort Nano Pouch			12 Week Nano Non-Pouch		
Unit No.	Condition	Rating	Unit No.	Condition	Rating	Unit No.	Condition	Rating
1	Intact	Pass	1	Intact	Pass	1	Intact	Pass
2	Intact	Pass	2	Intact	Pass	2	Intact	Pass
3	Intact	Pass	3	Intact	Pass	3	Intact	Pass
4	Intact	Pass	4	Intact	Pass	4	Intact	Pass
5	Intact	Pass	5	Intact	Pass	5	Intact	Pass
6	Intact	Pass	6	Intact	Pass	6	Intact	Pass
7	Intact	Pass	7	Intact	Pass	7	Intact	Pass
8	Intact	Pass	8	Intact	Pass	8	Intact	Pass
9	Intact	Pass	9	Intact	Pass	9	Intact	Pass
10	Intact	Pass	10	Intact	Pass	10	Intact	Pass
11	Intact	Pass	11	Intact	Pass	11	Intact	Pass
12	Intact	Pass	12	Intact	Pass	12	Intact	Pass
13	Intact	Pass	13	Intact	Pass	13	Intact	Pass
14	Intact	Pass	14	Intact	Pass	14	Intact	Pass
15	Intact	Pass	15	Intact	Pass	15	Intact	Pass
16	Intact	Pass	16	Intact	Pass	16	Intact	Pass
17	Intact	Pass	17	Intact	Pass	17	Intact	Pass
18	Intact	Pass	18	Intact	Pass	18	Intact	Pass
19	Intact	Pass	19	Intact	Pass	19	Intact	Pass
20	Intact	Pass	20	Intact	Pass	20	Intact	Pass
21	Intact	Pass	21	Intact	Pass	21	Intact	Pass
22	Intact	Pass	22	Intact	Pass	22	Intact	Pass
23	Intact	Pass	23	Intact	Pass	23	Intact	Pass
24	Intact	Pass	24	Intact	Pass	24	Intact	Pass
25	Intact	Pass	25	Intact	Pass	25	Intact	Pass
26	Intact	Pass	26	Intact	Pass	26	Intact	Pass
27	Intact	Pass	27	Intact	Pass	27	Intact	Pass
28	Intact	Pass	28	Intact	Pass	28	Intact	Pass

29	Intact	Pass	29	Intact	Pass	29	Intact	Pass
30	Intact	Pass	30	Intact	Pass	30	Intact	Pass

- **All Pouches were impervious to insect penetration or invasion.**

After 45 days of testing the cigarette beetles had time to produce a second generation of insects and all the food in the testing system had been exhausted. All three of the variables tested remained free of penetration holes. The Control Meal Bag has a smooth surface and the cigarette beetles seemed to have difficulty adhering to it during pupation. This was evident in the lack of pupal cases stuck to the pouches and the absence of marks attributed to mandibular scrapings (chew marks) by the model insect. The nanocomposite Meal Bag had 2 out of 30 pouches with chew marks. An example of this is shown in Figure 43.

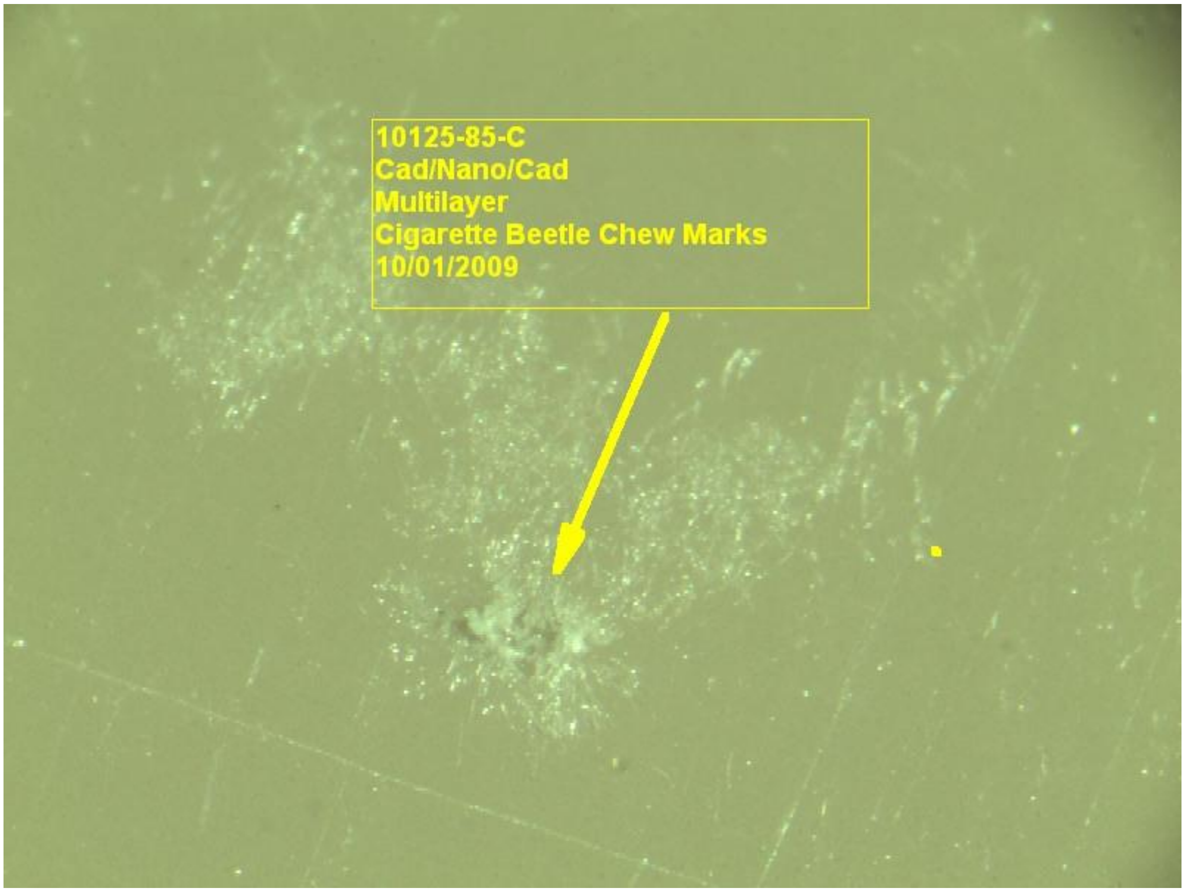


Figure 43. Insect infestation of the Meal Bag.

A criterion for success is that there is less than 20% penetration failure in comparison to the current MRE retort pouch.

Sixty pouches were made from each film sample. Each pouch was filled with 50 grams of stored-product insect diet (a mixture of ground dog food, brewer's yeast and powdered milk). Twenty pouches were placed inside three 18 gallon plastic storage totes.
Each tote represented a film type. 100 grams of insect diet was evenly spread over each pouches in all totes. 100 cigarette beetle adults (mixed sex) were added to each tote.
Study conditions were 80°±5° F and 60±5% relative humidity. Testing duration was 12 weeks. Twenty pouches per film type were removed at 4, 8 and 12 weeks. No failures at 4, 8 and 12 weeks.

Table 41. Insect Infestation of Control and Nanocomposite Retort Pouch

	4 Weeks		8 Weeks		12 Weeeks	
Bag No.	**Control**	**Nano Retort GL/KN**	**Control**	**Nano Retort GL/KN**	**Control**	**Nano Retort GL/KN**
1	Pass	Pass	Pass	Pass	Pass	Pass
2	Pass	Pass	Pass	Pass	Pass	Pass
3	Pass	Pass	Pass	Pass	Pass	Pass
4	Pass	Pass	Pass	Pass	Pass	Pass
5	Pass	Pass	Pass	Pass	Pass	Pass
6	Pass	Pass	Pass	Pass	Pass	Pass
7	Pass	Pass	Pass	Pass	Pass	Pass
8	Pass	Pass	Pass	Pass	Pass	Pass
9	Pass	Pass	Pass	Pass	Pass	Pass
10	Pass	Pass	Pass	Pass	Pass	Pass
11	Pass	Pass	Pass	Pass	Pass	Pass
12	Pass	Pass	Pass	Pass	Pass	Pass
13	Pass	Pass	Pass	Pass	Pass	Pass
14	Pass	Pass	Pass	Pass	Pass	Pass
15	Pass	Pass	Pass	Pass	Pass	Pass
16	Pass	Pass	Pass	Pass	Pass	Pass
17	Pass	Pass	Pass	Pass	Pass	Pass
18	Pass	Pass	Pass	Pass	Pass	Pass
19	Pass	Pass	Pass	Pass	Pass	Pass
20	Pass	Pass	Pass	Pass	Pass	Pass

6.2.10 Assure Integrity of Meal Bag After Environmental Rough Handling Results

Figure 44. Drop Tester

Table 42. Meal Bag defects at -17°.

Sample -17° F	Major Defects	Minor Defects	Percent Major Defect
Nanocomposite Bag	2	8	6%
Prototype Neat Bag	5	0	14%

Table 43. Meal Bag defects at 100°C.

Sample 100° F	Major Defects	Minor Defects	Percent Major Defect
Nanocomposite Bag	2	2	6%
Prototype Neat Bag	1	3	3%

This testing was conducted to determine compliance with the military specifications. Figure 44 shows drop tester equipment that was used for this evaluation. Further rough handling following ISTA methods for the unit load was presented in System Performance Objective section.

The success rate would be less than 15% failure. This has been met and was discussed in the System Performance objectives where the entire pallet was rough handled and the inspections were then conducted on the non-retort pouches as well as the Meal Bag and the retort food pouch. This is presented in Section.

6.2.10.1 Horizontal Impact Data

Table 44 Horizontal Impact Test: Pallet Marshalling Impacts - 1st Set

Nanocomposite Packaging (Meal Bag, Retort Pouch, Non-retort pouch)

Impact	Impact Side	Acceleration	Duration	Velocity Change
1	Long	8.24 g	24.3 msec	41.5 in/s
2	Short	8.21 g	24.2 msec	41.8 in/s
3	Opposite Long	8.37 g	24.4 msec	42.4 in/s
4	Opposite Short	8.37 g	24.4 msec	42.4 in/s

Control

Impact	Impact Side	Acceleration	Duration	Velocity Change
1	Long	8.03 g	24.2 msec	40.9 in/s
2	Short	8.03 g	24.2 msec	40.9 in/s
3	Opposite Long	8.15 g	24.3 msec	41.7 in/s
4	Opposite Short	8.28 g	24.4 msec	42.1 in/s

Table 45 Vertical Impact Test: Edge Drops - 1st Set

Drop	Impact Edge	Drop Height	Opposite Edge Raised
1	Long	8 inch	4 inch
2	Short	8 inch	4 inch

Table 46. Vibration Test: Random Vibration

Test	Profile	Duration	Intensity
1	ISTA 3H Steel Spring Control on bottom	120 minutes	0.54 g_{rms}
2	ISTA 3H Steel Spring GLKN on bottom	120 minutes	0.54 g_{rms}

Table 47. Vertical Impact Test: Edge Drops - 2nd Set

Both Pallets

Drop	Impact Edge	Drop Height	Opposite Edge Raised
3	Opposite Long	8 inch	4 inch
4	Opposite Short	8 inch	4 inch

6.2.10.2 Pre-Test Inspection

The stretch wrap was torn in a few places upon arrival (Figure 45) so all stretch wrap was replaced. The Control A pallet arrived without three long side bands. Pira added the bands prior to re-stretch wrapping the Control A unit load. The nanocomposite pallet was equipped with the three long side bands. The rewrapped unit load is shown in Figure 46 .

Figure 45. Damaged Stretch Wrap Upon Arrival (Each unit was rewrapped prior to testing).

Figure 46. Example of New Bands Placed on the Long Side of the Control A Pallet at Pira.

6.2.10.3 Test Observations

The top layer of the Control shifted slightly during vibration, however, did not cause any further issues during testing. Both unit loads performed very well throughout all the testing. The nanocomposite pallet broke during the rotational drop test but did not affect the remainder of the test.

Figure 47. Broken Pallet During the Rotational Edge Drop (GL/KN Unit Load).

Figure 48. Test Cases After Testing.

6.2.10.3 Meal Bag Inspection Results

Once all laboratory testing was completed the unit loads were inspected for outside damage to the unit load with critical defects noted, in this case the control containers only showed minor exterior damage due to handling compression and vibration to include minor compression marks on the solid fiberboard containers. In total, 528 individual rations were inspected for signs of visible damage. One case, randomly selected from each layer was excluded from the evaluations in order to keep the sample size per layer consistent throughout the study. During the inspection of the control meal bags, three types of defects in the meal bag were identified which included pinholes, failure of the peelable seal, partial bursting of the peelable seal and stress whitening. The remaining samples, totaling 499 meal bags or 94.5% of the sample set had no visible damage to the meal bag. Thirty eight control samples were found to have no visible defects to the two sealing area and body of the meal bag. The failures were classified as minor and are deemed to have little influence on the effective use of the unit product. The two defect types that exposed the internal components to the outside environment included pinholes and bursting of the peelable seal. Pinholes are described as punctures or tears that penetrate through all layers of the structure, exposing the internal components. Pinholes are often created by the sharp edges and corners of internal components and are even created by the retort paperboard carton. This type of defect is often the resul of excessive material handling, case packing operations and high impact events during distribution. The failure of the peelable seal was the most common defect and often results from expansion of entrapped air during high altitude transport and high impact events that cause product movement and rapid compression of entrapped air which normally escapes through the peelable seal. Partial bursting of the seal and stress whitening of the material were the two other defects identified during the inspection both of which are often a precursor to more extensive failure. Partial bursting or seal creep of the peelable seal is often caused by a buildup of internal pressure due to high altitude environments or high impact events. During this demonstration, a high impact event was observed when the test samples impacted the pavement, causing a rapid buildup of internal pressure. In comparison to the thinner nanocomposite meal bag the control bag had similar numbers of samples with no visible defects. The control had more instances of failure at the peelable seal and is possibly the result of improper bonding between material during manufacturing or resulted from the type and degree of impact encountered during the demonstration. As expected, the thicker control meal bag offered better resistance to puncture and tearing events.

During the meal bag packaging inspection of the low velocity airdrop samples (loads 4, 5, and 6), three types of defects were identified which included pinholes, failure of the peelable seal, and stress whitening as shown. The control meal bag was found to have two types of minor defects in the packaging which included pin holing and bursting at the peelable seal. Failure of the 11 mil film structure through pin holing was the most common defect found in the control samples. As shown, incidents of pinhole failure were highest in load 4 with 6.3% of samples showing this type of package defect. Failure of the peelable seal was also identified as a minor defect with only one incidence of occurrence in load 4. Stress whitening of the material through mechanical stresses was also noted as a packaging defect but was not deemed critical to the overall performance of the meal bag structure. All samples inspected contained incidences of stress whitening but quantifying the rate of occurrence and degree of stressing was deemed too to quantify but was noted within the inspection sheets.

Thirty eight control samples were found to have no visible defects to the two sealing area and body of the meal bag. The failures were classified as minor and are deemed to have little influence on the effective use of the unit product. The two defect types that exposed the internal components to the outside environment included pinholes and bursting of the peelable seal. Pinholes are described as punctures or tears that penetrate through all layers of the structure, exposing the internal components. Pinholes are often created by the sharp edges and corners of internal components and are even created by the retort paperboard carton. This type of defect is often the resultant of excessive material handling, case packing operations and high impact events during distribution.

The failure of the peelable seal was the most common defect and often results from expansion of entrapped air during high altitude transport and high impact events that cause product movement and rapid compression of entrapped air which normally escapes through the peelable seal.

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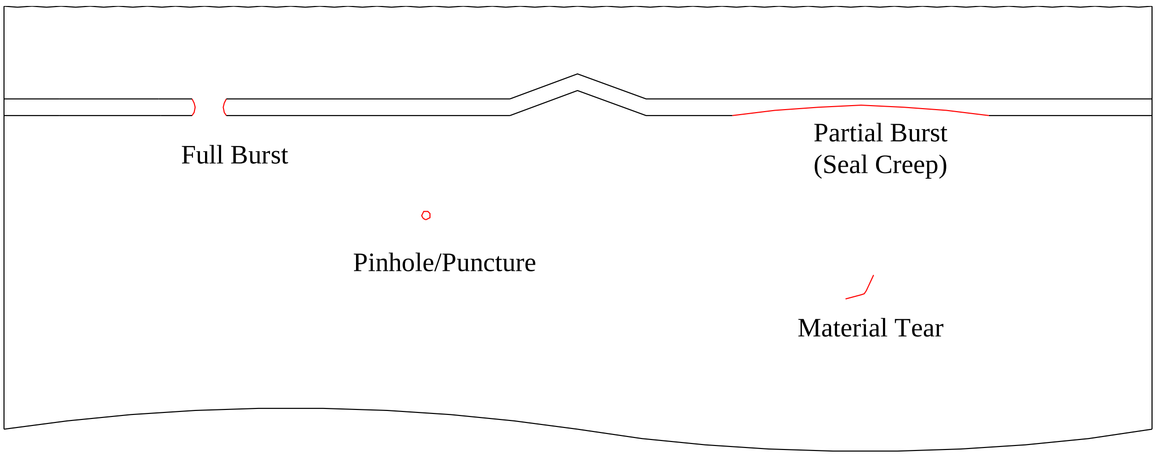

Figure 49. Meal Bag Defects (burst, partial burst, pinholes and tear)

6.2.10.4 Post-Test Inspection Summary for Nanocomposite Packaging

6.2.10.4.1 Retort Pouch Three (3) failures out of 576 were found in the retort pouch:
Seal failures due to food entrapment were found in various cases.
No (zero) seal failures were found on the prototype retort material.
Stress whitening was often found throughout the retort pouch, and was concentrated in areas where the carton had been compressed. Some stress whitening was found at the tear notch of the retort pouch

6.2.10.4.2 Non-Retort The non-retort (pretzel) pouch had a puncture mark on two of the pouches, which are most likely a process issue and not a result of the distribution testing. Salt impressions were commonly found in the non-retort (pretzel) pouch for. Pin holes from the carton of the retort pouch were found in one meal bag.

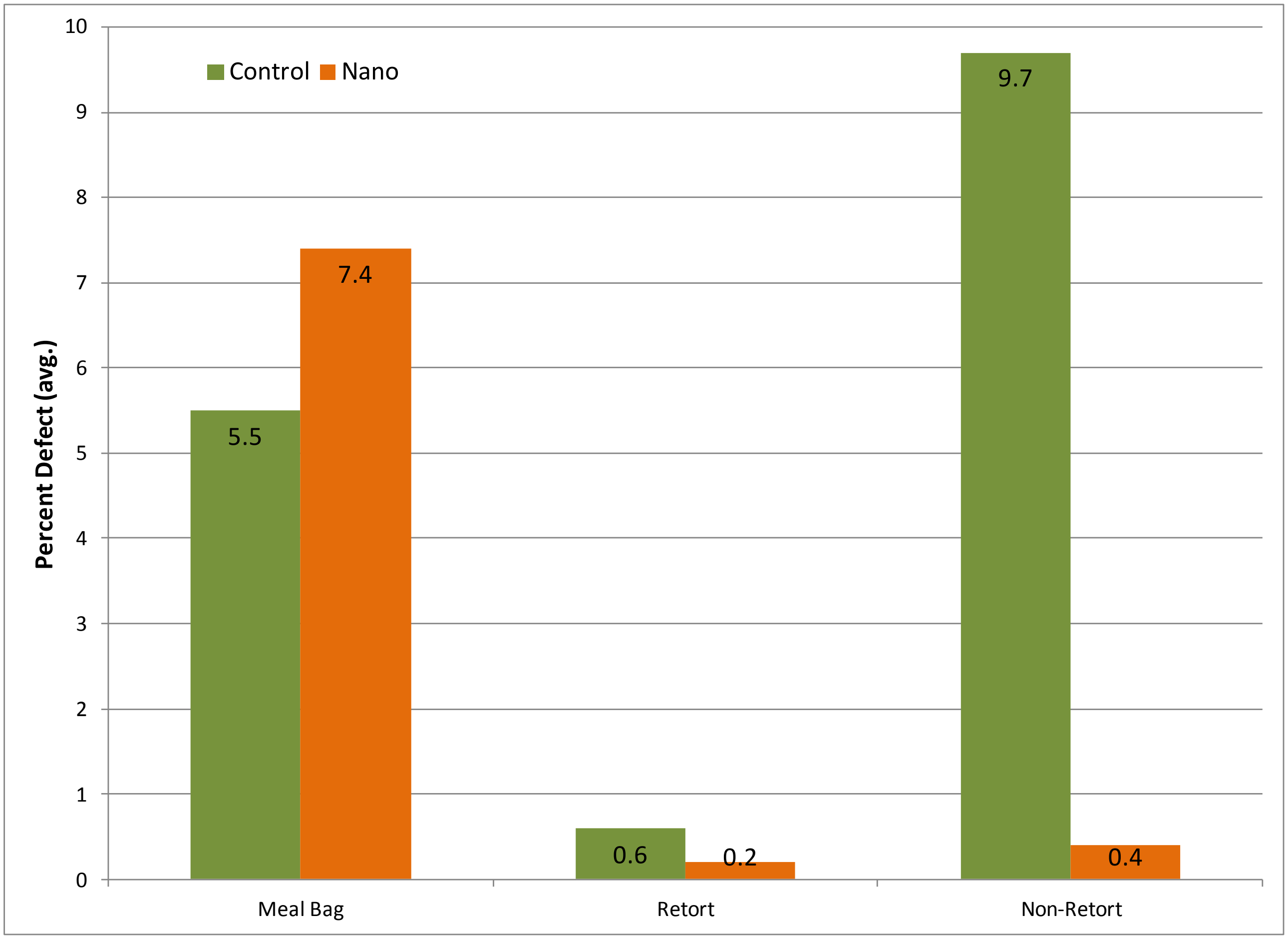

Figure 50. Meal Bag, Retort Pouch and Non-Retort Pouch Percent Defects for Nanocomposite and Control Samples.

Table 48. Defect Summary of Test Samples

		Layer 1	Layer 2	Layer 3	Layer 4	Total	% Avg.
Control	**Meal Bag**	9	6	4	10	29	5.5
	Retort	2	0	0	1	3	0.6
	Non-Retort	12	14	14	11	51	9.7
Nano	**Meal Bag**	6	12	15	6	39	7.4
	Retort	1	0	0	0	1	0.2
	Non-Retort	0	0	1	1	2	0.4

The nanocomposite retort pouch showed signs of stress whitening of the pouch and was common for items that were handled roughly during testing as shown in **Figure** 50

Figure 51. Prototype Retort Pouch with Slight Stress Whitening (highlighted in red).

Two of the major causes of pouch failure are improper filling and sealing. However, the filling and sealing were verified at AmeriQual in their quality control testing. Manufacturer's seals were also should have been validated by the manufacturer of the pouches. Contamination of the manufacturer's seal area is a common problem that affects the hermetic seal of the flexible pouch. Incorrect vacuum or improper pouch handling is the two primary causes of this problem. For liquid products, too high a vacuum could suck product into the seal area just before heat sealing which could affect the integrity of the seal. Also, improper handling of empty pouches on-line could result in contamination of the seal during filling. Entrapped food particles or contamination of seal areas seriously reduces seal strength reliability. Incorrect handling of pouches during processing and post process could also cause physical damage to the pouch and seal, which could weaken the seal or compromise the hermetic seal of the pouch.

Figure 52 highlights food entrapment at the manufactured seal which normally occurs during product filling and end item sealing. The seals are normally bonded securely but food entrapment may lead to premature failure at the manufactured seal as the seal is weakened and or not properly bonded.

Figure 52. Control A Retort Pouch Containing Entrapped Food Within the Manufactured Seal.

The nanocomposite retort pouch showed signs of stress whitening throughout the body of the pouch but did not lead to leaking or product failure as shown in Figure 53.

Figure 53. Prototype Retort Pouch with Slight Stress Whitening.

Figure 54 highlights an occurrence of food entrapment at the manufactured seal. Entrapment of food particles can occur for retort items but normally does not lead to premature failure.

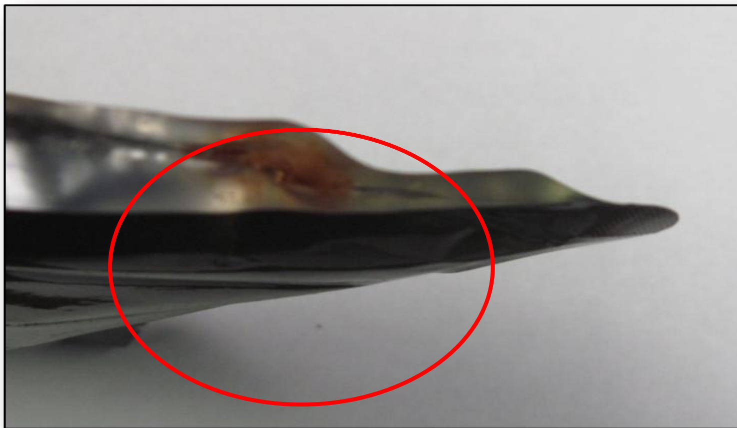

Figure 54. Control A Retort Pouch with Food Entrapment in the Manufactured Seal

Figure 55 highlights an occurrence of seal failure at the peelable seal. The peelable seal is normally the weaker of the two seals and often times shows signs of stress at the seal edge, seal creep (partial burst) or bursting of the seal. Entrapped air within the meal bag is the primary root cause of package failure. During impact or rough handling the meal bag is often compressed and the entrapped air stresses the seal and or breaks it prior to consumption.

Figure 55. Control A Meal Bag with Seal Failure at the Peelable Seal.

Figure 56. Prototype Non-Retort Pouch with Abrasion Mark.

During the inspection, two nanocomposite non-retort pretzel pouches contained a similar abrasion mark and is highlighted in Figure 56. The damage to these two samples probably occurred during the filling/assembly process at the ration assembly facility. In both instances no penetration into the pouch occurred and only showed signs of a surface abrasion.

Figure 57. Retort Pouch with Stress Whitening at the Tear Notch.

The nanocomposite retort pouch showed signs of premature failure at the tear notch locations. As highlighted in Figure 57, the tear notch shows signs of stress whitening and premature tearing. Once a tear is initiated it may continue through the seal and expose the enclosed product. Alternative notch designs may eliminate occurrence of failure and may include a “U” notch design or a “C” notch design which may lower the stress concentration at the notched area location.

Test/evaluation is critical in determining whether or not the prototype nanocomposite packaging could withstand rough handling and cold weather storage conditions. Visual inspections of failed packaging and identification /documentation of failure modes were the major focus of the inspection.

6.2.11 Compression Results

The control test pallet was loaded with 12,014 lbs of weight, once the test sample reached the calculated weight of approximately 12,008 lbs the platen was removed from the unit load. At the peak force the total amount of deflection reached 1.16 inches across the four layers of ration containers. No signs of severe damage were reported on the control pallet. As shown in the**Table 49 Compression Test Data.**Table 49, the control load reached a deflection of 1.16 in, while the control samples reached a slightly higher deflection of 1.16 inches. The nanocomposite pallet was loaded with 12,023 lbs of weight, once the test sample reached the calculated weight of approximately 12,008 lbs the platen was removed from the unit load. At the peak force the total amount of deflection reached 0.99 inches across the four layers of ration containers, which in comparison to the controls was slightly less. No signs of container damage were reported on the nanocomposite pallet. As shown in Figure 58, the compressive load versus deflection was recorded on an X-Y plot which highlights the response of each test sample to the applied load. As the plots show, both pallet loads exhibit similar responses and both had no evidence of damage/failure due to the unit load deformation.

Table 49 Compression Test Data.

Test Sample	Peak Force (lbs)	Defl. at Peak (in)	Preload (lbs)	Test Speed (in/min)	Temp. (F)	% RH
MRE Control	12,014	1.16	250	0.5	68.4	44.5
MRE Nanocomposite	12,023	0.99	250	0.5	68.3	44.5

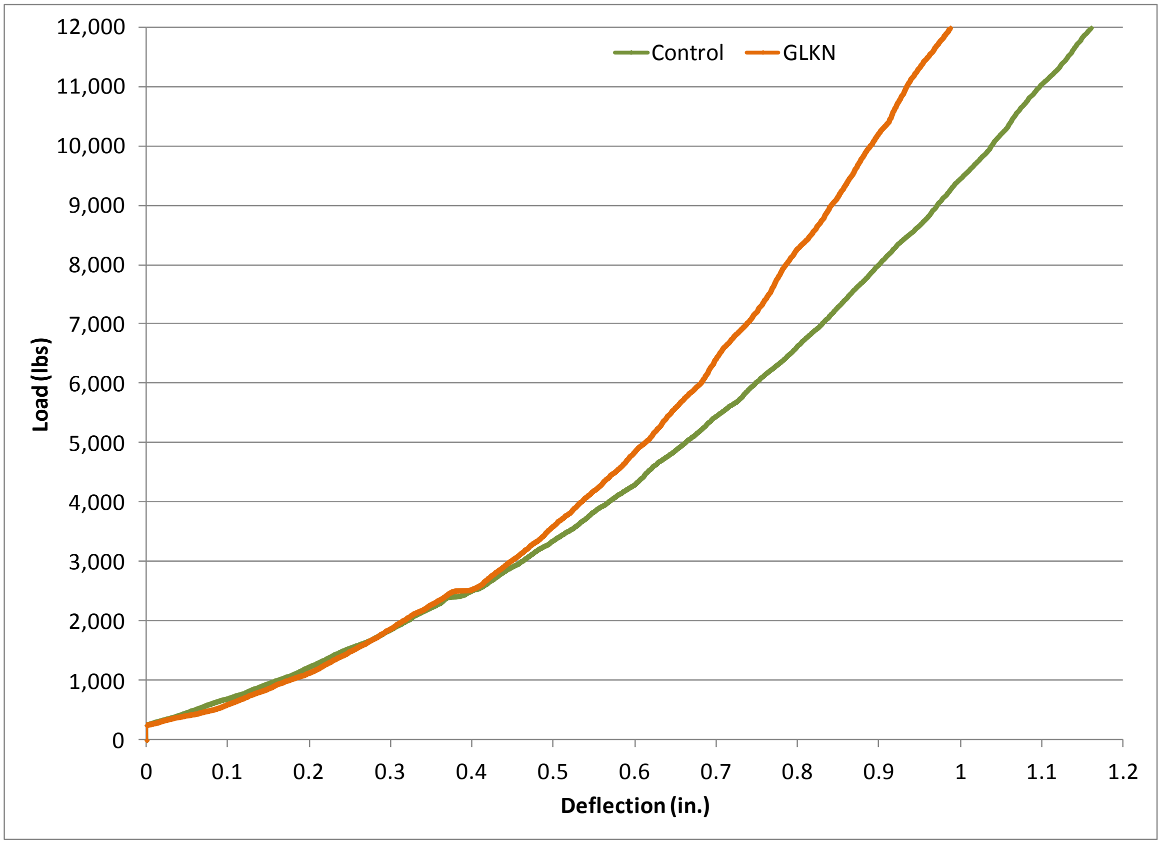

Figure 58. Unit Load Compression Results (orange plots–Nanocomposite and green plots–Control)

6.3 FIED TEST RESULTS

6.3.1 Field Test

Demographics: The participants range in age from 19 to 50, with a mean age of 27. Most of the participants were male, and 21.4% were female. The participants hailed from a variety of locations across the United States, and represented a wide variety of Military Occupational Specialties. All of the participants were Enlisted soldiers, the majority being E-4s or E-5s. All of the participants had had MREs before, and 52.7% reported that they ate MREs in the field more than half of the time; 41.5% ate from the chow line half of the time. Detailed demographic information was included at the end of the report.

MRE Questionnaire: The soldiers completed questionnaires at each meal for the MRE they were issued over the course of the evaluation. The analyses of these data are presented below.
Acceptability (liking) of the entrée and the pretzels was rated on a 9-point scale. The soldiers rated how much they liked the Spicy Penne Pasta and the Pretzels under each of the three packaging conditions. A Oneway analysis was performed on these data. There are no statistically significant differences in how acceptable (likable) the penne or the pretzels are under the three different conditions..

Table 50. Field study: Acceptability (liking).

Entrée Retort Pouch	Control	GL/KN Nano Retort
	718	728
Mean	6.08	6.25
Std. Deviation	1.832	1.833
N	95	100

Pretzels Non-retort Pouch	Control	Nano non-retort
	718	728
Mean	6.92	6.66
Std. Deviation	1.651	1.688
N	90	94

No significant differences (Oneway $p > 0.05$).

Dislike Extremely	Dislike Very Much	Dislike Moderately	Dislike Slightly	Neither like Nor Dislike	Like Very Much	Like Extremely
☐	☐	☐	☐	☐	☐	☐

The ease of opening the packaging was rated on a 7-point scale. The soldiers rated how easy / difficult it was to open the MRE bag, the retort bag, and the non-retort bag, under the three conditions. A Oneway analysis and post hoc tests were run on these data. As shown in Table 51, the ease of opening ratings for the current MRE bag (somewhat difficult/neutral) was lower ($p < 0.05$) than the rating for the Nanocomposite Meal Bag (neutral/somewhat easy). There were no other significant differences. While in the field, the investigators noticed that the MRE meal bag was sealed so that there was more to grip on the “wrong” or non-peelable end of the MRE, and the soldiers were inclined to open the MRE from that end. The investigators explained to the soldiers how to identify the peelable end of the MRE.

Table 51. Field study: How easy/difficult was it to open the MRE meal bag?

	Mean	Std. Deviation	N
Meal Bag Control[1,2]	3.88	1.939	98
Meal Bag Nano [1]	4.80	1.886	103

Post hoc: significant differences ($p < 0.05$) are indicated by superscripts.

Very Difficult	Moderately Difficult	Somewhat Difficult	Neutral	Somewhat Easy	Moderately Easy	Very Easy
1	2	3	4	5	6	7

The ease of opening rating for the current retort bag (neutral/somewhat easy) was lower ($p < 0.05$) than the ratings for the GL/KN nano (somewhat/moderately easy). There were no other significant differences.

Table 52. Field study: How easy/difficult was it to open the Entrée (retort pouch)?

	Mean	Std. Deviation	N
Control retort pouchl[1,2]	4.79	1.628	92
Nano Retort pouch GL/KN [1]	5.66	1.364	99

Post hoc: significant differences ($p < 0.05$) are indicated by superscripts.

The ease of opening rating for the current non-retort bag (somewhat/moderately easy) is lower ($p < 0.05$) than the GL/KN nano bag (moderately easy.

Table 53. Field study: How easy/difficult was it to open the Pretzels (non-retort pouch)?

	Mean	Std. Deviation	N
Control[1]	5.32	1.518	94
Nano Meal Bag[1]	5.94	1.272	96

Post hoc: significant differences ($p < 0.05$) are indicated by superscripts.

Satisfaction with the temperature of the entrée was rated on a 7-point scale. Flameless Ration Heaters (FRH) were included in all of the meals. When the soldiers used the FRH to heat their entrees, they were asked to rate how satisfied they were with the temperature of the heated entrée, and to describe any problems they encountered while heating their entrée. Two thirds of the entrees were heated with the FRH. A Oneway analysis and post hoc tests showed that the satisfaction with temperature rating for the entrees was significantly lower ($p < 0.05$) for the current packaging (neutral/somewhat satisfied) than nanocomposite packaging (somewhat/moderately satisfied).

Table 54. Field study: Satisfaction with the Temperature for Retort Pouch

	Mean	Std. Deviation	N
Control	4.76	1.723	75
GL/KN nano	4.99	1.556	89

Very Dissatisfied	Moderately Dissatisfied	Somewhat Dissatisfied	Neutral	Somewhat Satisfied	Moderately Satisfied	Very Satisfied
1	2	3	4	5	6	7

Under all three conditions there were a few comments that the retort bag was too big for the FRH bag (or that the FRH bag was too small).

There were a few reports of damaged packages where the entrée was leaking or broken open. Damage was rarely reported and occurred with all three types of packaging.

Table 55. Field study: Reported Damage.

		Control 718 Count	Nano Packaging 728 Count
Was the MRE bag damaged at all?	No	100	105
	Yes	1	0
Was the Entree bag damaged at all?	No	101	104
	Yes	1	1
Was the Pretzels bag damaged at all?	No	99	105
	Yes	2	0

On every questionnaire there was space set aside for any general comments the participating soldiers wanted to make about the MRE bag, the entrée bag and the pretzel bag they were issued that day. On most questionnaires, no comments were made. Other times, the respondent's comment included more than one point. Each point was counted individually, so the numbers on the following tables may not add up perfectly.

MRE Meal bag: Fourteen commented that the Nano Meal Bag was easy to open,. Twelve said that the current MRE bag was difficult to open.

Table 56. Field Study: MRE Meal Bag comments.

	Current	Nano Meal Bags
blank	75	76
easy to open	7	14
difficult to open	12	7
good	1	3
durable	2	0
no difference	1	1
Label peelable side	0	2
too big	1	0
bulky	0	1
change color	1	0
noisy	0	1
good seal	1	0
lighter	0	0
rips	1	0
sideways	0	0
smaller and thinner	0	1

Retort (entrée) bag: Fourteen commented that the Non Retort pouch entrée bag was easy to open. Ten commented that they like the clear packaging for the entree.

Table 57. Field study: Retort Pouch (Entrée) Comments.

	Control	Nano Retort GL/KN
blank	79	77
easy to open	7	14
like clear	2	8
difficult to open	4	0
good	2	1
dislike clear	0	1
durable	2	1
no difference	2	1
change color	1	1
messy	0	1
not durable	1	1
open lengthwise	2	0
cleaner	0	1
safer	0	1
ugly	0	0
easy to use with heater	0	1
good seal	0	0
noisy	0	1

Non-retort (Pretzel) bag: There are ten comments that the Nano pretzel bag was easy to open.

Table 58. Field Study: Non-retort (Pretzel) Bag Comments

	Control Non-retort	Nano Non-retort
blank	77	77
easy to open	8	10
good	5	3
like clear	0	1
noisy	0	1
change color	1	1
difficult to open	0	1
dislike	0	2
easy to use	0	1
clean	0	0
durable	0	1
quiet	1	0
small	1	0
too small	0	1

Post-Evaluation Questionnaire: This questionnaire was filled out by the participants at the end of the field evaluation. Ninety-one participants completed this questionnaire, normal attrition accounting for the drop outs.

With respect to liking/disliking of the transparent entrée packaging, 58.3% of respondents expressed a degree of liking, 22.0% neither liked nor disliked, while 12.1% expressed a degree of disliking (Table 10). The mean rating is 6.03 (N=91, STD.=2.27) which roughly translates to 'like slightly'.

With respect to liking/disliking of the transparent pretzel packaging, 57.2% of respondents expressed a degree of liking, 32.6% neither liked nor disliked, while 10.0% expressed a degree of disliking (Table 59). The mean rating is 6.3 (N=89, STD.=2.07) which roughly translates to 'like slightly'. See for full detail. Measures of liking/disliking for the transparent packaging for both the entrée and the pretzels are remarkably similar.

Table 59. Field Study Questions: How much do you like / dislike having MRE items in transparent packaging?

	Entrée (Retort Pouch)	**Pretzels (Non-retort Pouch)**
Mean	6.03	6.30
Std. Deviation	2.27	2.07
Valid N	91	89

When asked to choose between transparent packaging and solid color packaging for the Entrée, 57.1% chose the transparent package while only 5.6% preferred the solid color. 34.1% had no preference for either. When posed the same question for the Pretzels, the data looked remarkably similar as shown below.

Table 60. Field Study Questions, Given the choice, would you rather have transparent packaging, or solid color
packaging?

	Percent Prefer			
	Transparent	Solid Color	No Preference	N
Entrée (retort)	57.1	5.6	34.1	88
Pretzels (non-retort)	52.3	5.6	42.2	90

When asked for suggestions for the MRE packaging, the retort pouch (Entrée) and the non-retort pouch (pretzels), most of the time there were no comments. All such comments are listed in Table 61, Table 62 and Table 63.

Table 61. Field Study Suggestions: Suggestions About the Outer MRE packaging.

	N
blank (no comment)	62
easy to open	3
make it transparent	3
make it easier to open	3
make it open length wise	2
vacuum seal to reduce size, should fit in cargo pockets	2
include hot sauce	1
keep it as is	1
label the open side	1
no veggie omelets	1
more skittles	1
include smores	1
include straws	1
include cigarettes	1
longer spoon	1
don’t need 2 bags, thick outer shell and clear plastic	1
include nutrition facts/total calories	1
make package resealable	1
this test was an interruption to our training	1
change color to a pattern	1
don’t care	1
no transparency, I like the surprise	1
Total N	91

Table 62. Field Study Suggestions: Suggestions About the Entrée (Main Dish) Packaging.

	N
blank (no comment)	62
transparent is better	6
make it open length wise	6
no transparent packaging, it looks gross	2
make it easy to open	2
chicken and dumpling very good	2
don't make airtight	1
include hot sauce	1
it was easier to open	1
include nutrition facts/total calories	1
make it tastier	1
make it open closer to top of package so food doesn't spill out when you open it	1
some were easier to open than others	1
make it resealable	1
don't care	1
Total N	89

Table 63. Field Study Suggestions: Suggestions About the Pretzel Packaging.

	N
blank (no comment)	80
good	2
i like the pretzel	2
transparent is better	2
more salt/flavor	1
reduce excess packaging to reduce waste	1
very noisy	1
add cheese	1
easy to open solid packaging	1
Total N	91

Based on the data collected during this field evaluation, we may conclude that both versions of the test packaging are at least as good as the control packaging, in terms of the flavor of the packaged food, ease of opening the packaging, and satisfaction with the temperature of the heated retort item.

When nanocomposite packaging is compared with the control it has higher ratings for ease of opening the MRE bag and the retort bag. It is as good as the control packaging in terms of ease of opening the non-retort bag and satisfaction with temperature.

Damage was rare for all packages. Few people objected to having clear packaging for their entrée and snacks. Over half preferred the clear packaging and the rest had no strong feelings about clear packaging. We may conclude that clear packaging could be adopted for both retort and non-retort MRE packaging.

Based on this field evaluation, the ratings for the nanocomposite GL/KN these options do not exceed the ratings for the control packaging, they are rated as being as good as the control packaging. Either could be adopted while maintaining or exceeding the current quality of the MRE packaging.

Table 64. Overview of the Field Study Results

	Nanocomposite	**Control**	**Notes:**
Acceptability of the food	ND	ND	No difference
Ease of opening			
Meal bag	+ than control		All supported by written comments
Retort bag	+ than control		
NonRetort bag			
Satisfaction with temperature			
Damage	rare	rare	

6.3.1.1 Detailed Demographic Information

The pre-evaluation was filled out by 112 respondents at the NCO Academy (Reserves) at Joint Base Lewis-McChord, WA. Mean age across all respondents was 27 with 75% below the age of 30. Ages ranged from 19 to 50. Most (78.6%) of the respondents were male and 21.4% were female soldiers.

In response to the optional ethnicity and race questions, 62.5% answered that they were *not* Hispanic or Latino, 18.8% described themselves as Hispanic or Latino, and 18.8% opted to not answer this question. Most (71.4%) of respondents described themselves as White, 7.1% as Black, 6.3% as Asian, 3.6% as Native Hawaiian/Pacific Islander and 2.7% as American Indian/Alaskan Natives. Twelve percent (11.6%) opted to not answer this question.

The bulk of this group (42.0%) spent most of their lives growing up the Pacific region, of the United States, followed by 25% in the North Central region. Three grew up outside of the United States (Egypt, Mexico, and the Philippines). See Table 65 for more detailed breakdown.

Table 65. Field Study Question: In what part of the US did you live the longest before the age of 16?

	%	N
Pacific (AK, CA, HI, OR, WA)	42	47
North Central (IA, IL, IN, KS, MI, MN, MO, ND, NE, OH, SD, WI)	25	28
New England (CT, MA, ME, NH, RI, VT)	0.9	1
South Central (AL, AR, KY,LA, MS, OK, TN, TX)	8.9	10
Middle Atlantic (DE, MD, NJ, NY, PA)	8.9	10
Mountain (AZ, CO, ID, MT, NM, NV, UT, WY)	8	9
South Atlantic (DC, FL, GA, NC, VA, WV, SC)	4.5	5
Other	2.7	3
US Territories (FM, GU, MH, MP, PW, PR, VI)	0	0

Over half (52.7%) reported eating MREs in the field *more* than half of the time, and 30.0% report eating MREs half of the time. No respondents report that they never eat MREs in the field. Over forty percent (41.5%) report eating from the chow line half of the time, and 37.7% report eating from the chow line *more* than half of the time. No respondents report that they never eat from the chow line. In addition, 15.3% of respondents answered an 'Other' option. Nearly 10% of respondents report bringing their own food into the field.

Table 66. Field Study Question: When you are in the field, how often do you eat the following rations?

	Never	Never	Seldom	time	Often	Always	Always	N
MRE	0	7.3	10	30	31.8	7.3	13.6	110
Chow Line	0	2.8	17.9	41.5	25.5	4.7	7.5	106

other (write in)	N
bring my own food	11
local cuisine	3
pogie bait	1
only when i like it	1
in mob chow ½ time	1

All of the respondents were enlisted; the bulk of which were E-4’s (54.5%) and E-5’s (42.9%). The remainders are either E-3’s (1.8%) or E-6’s (0.9%). Because this is the NCO Academy, none of the respondents were Warrant Officers or Officers.

6.3.2 Reduce Amount of Solid Waste Requiring Disposal

The objective was to reduce the amount of solid waste requiring disposal and this has substantial relevance to the demonstration for the overall goal to reduce solid waste.

Studies have shown that solid waste is generated at a rate of about 4 lbs per person per day for Force Provider camps and Army field exercises, most of which originates from foodservice operations. This is relevant to the demonstration as the overall goal of this environment demonstration is to reduce the amount of solid waste for the military. Deployed forces and contingency operations generate tons of solid waste that must be burned or backhauled to disposal sites at great expense. The metric to assess is the tons/day of ration waste generated by the military. Size and weight comparisons of the packaging components are shown in

Meal Bag		Retort Pouch		Non-Retort Pouch	
Control	**Nanocomposite**	**Control**	**Nanocomposite**	**Control**	**Nanocomposite**
					
Thickness (mil)					
10.92	7.05	5.12	5.50	4.02	5.80
Size (mm)					
350 x 221	350 x 221	204 x 118	204 x 118	210 x 126	210 x 126
Weight (g)					
39.92	25.43	6.90	6.42	5.68	7.75
Percent Weight Reduction (%)					
-	36.3	-	7.0	-	-36.3

Figure **59**. A characterization study generating the amount (weight) of the disposed solid waste is necessary. The success would be if there is a greater than 30% reduction in the solid waste with 10% being able to be recycled.

Meal Bag		Retort Pouch		Non-Retort Pouch	
Control	Nanocomposite	Control	Nanocomposite	Control	Nanocomposite
					
Thickness (mil)					
10.92	7.05	5.12	5.50	4.02	5.80
Size (mm)					
350 x 221	350 x 221	204 x 118	204 x 118	210 x 126	210 x 126
Weight (g)					
39.92	25.43	6.90	6.42	5.68	7.75
Percent Weight Reduction (%)					
-	36.3	-	7.0	-	-36.3

Figure 59. Size and weight Comparisons of the MRE Packaging Components to Include the Meal Bag, Retort Pouch and Non-Retort Pouches.

Table 67. Data for Weight Calculations

Packaging Weight Reduction Estimates

	Meal Bag		Retort Pouch		Non-Retort Pouch	
	Control	**Nanocomposite**	**Control**	**Nanocomposite**	**Control**	**Nanocomposite**
Sample 1 Weight (g)	0.1285	0.0806	0.0725	0.0678	0.0546	0.0762
Sample 2 Weight (g)	0.1311	0.0821	0.0720	0.0671	0.0561	0.0736
Sample 3 Weight (g)	0.1293	0.0851	0.0733	0.0677	0.0526	0.0728
Average Weight of Sample (g)*	0.1296	0.0826	0.0726	0.0675	0.0544	0.0742
Length of Pouch (mm)	353.00	353.00	204.00	204.00	210.00	210.00
Width of Pouch (mm)	221.00	221.00	118.00	118.00	126.00	126.00
Area of Pouch (mm^2)	78013	78013	24072	24072	26460	26460
Estimated Weight of Pouch (g)	**39.92**	**25.43**	**6.90**	**6.42**	**5.68**	**7.75**
Estimated Weight Savings per Pouch (g)	-	14.48	-	0.48	-	-2.06
Estimated Weight Savings per Pouch (lb)	-	0.0319	-	0.0011	-	-0.0045
Estimated Weight Savings per Case (lb)	-	0.38	-	0.01	-	-0.05
Estimated Weight Savings per Unit Load (lb)	-	18.4	-	0.6	-	-2.6
Estimated Weight Savings per Trailer (lb)	-	699	-	23	-	-100
Percent Reduction of Material (%)	-	36.3%	-	7.0%	-	-36.3%

Note: Information used for the estimated weight savings calculations: 12 rations per case, 576 rations per unit load21,888 rations per truck load or 38 unit loads, and 43,000,000 rations in one procurement year. *Sample circle cutout with radius of 12.7 mm and area 506.71 mm^2.

Packaging weight calculations were estimated by obtaining the average weight of a known area (circle cutout with a radius of 12.7 mm) and integrated with the actual size of a standard pouch to obtain a comparative weight analysis of the control packaging and nanocomposite packaging items, as shown in Table 67. The following calculations were used to obtain the estimated total weight of each package: $W_p = (W_c / A_c) \times (A_p \times 2)$; where W_p is the estimated total weight of a pouch, W_c is the weight of the circle cutout, A_c is the area of the circle cutout (506.71 mm^2), A_p is the area of the standard pouch size calculated by multiplying the length and width of each pouch and a constant (2) to account for the total material used to construct the two sides of each pouch.

Once the estimated total weights were obtained the percent reduction was calculated for each the meal bag, retort pouch and non-retort pouch items. The weight reduction estimates per pouch were also used to calculate the weight.

6.3.3 Assure MRE Can Withstand Air Drops

Figure 61 and Figure 62 show the shock events introduced by the aerial delivery of MRE unit loads. Once the load was separated from the aircraft airflow the parachute began to open, creating a sudden deceleration on the load. This event was characterized by a relatively long deceleration of the load as the parachute went from a partial opening to a full opening of the parachute's canopy. This phase of the descent was characterized by the deceleration created by the opening of the parachute and the loss of forward velocity as a result; this phase was readily identified by the data recorders. Loads can experience high levels of deceleration in multiple directions as the load whips around, in an effort to "right" itself during descent.

Once the parachute fully deployed and the forward velocity slowed the unit load was then in the descent phase. Most of the unit loads obtained full deployment of the parachute during this phase and showed oscillations between the unit load and the parachute as the unit load descended to the drop zone. Not all loads reached full deployment of the parachute which may have been influenced by a combination of events or environments that included aircraft airflow, interaction with other loads and the altitude of the airdrop. The airflow directly behind the aircraft was very turbulent and may have caused a parachute to open later than intended; also it may have been positioned in close proximity to other units loads in which they both competed for "air" to open the parachute. Several loads opening at once may have "starved" a load of air needed to open the parachute, thus delaying full deployment. And coupled with a low altitude drop this starved load may have descended much faster that the fully deployed units and may not have had time to fully deploy prior to impact. This scenario was seen in unit load number eight, in which the parachute did not fully deploy until only seconds before impact, which was characterized by a high level impact.

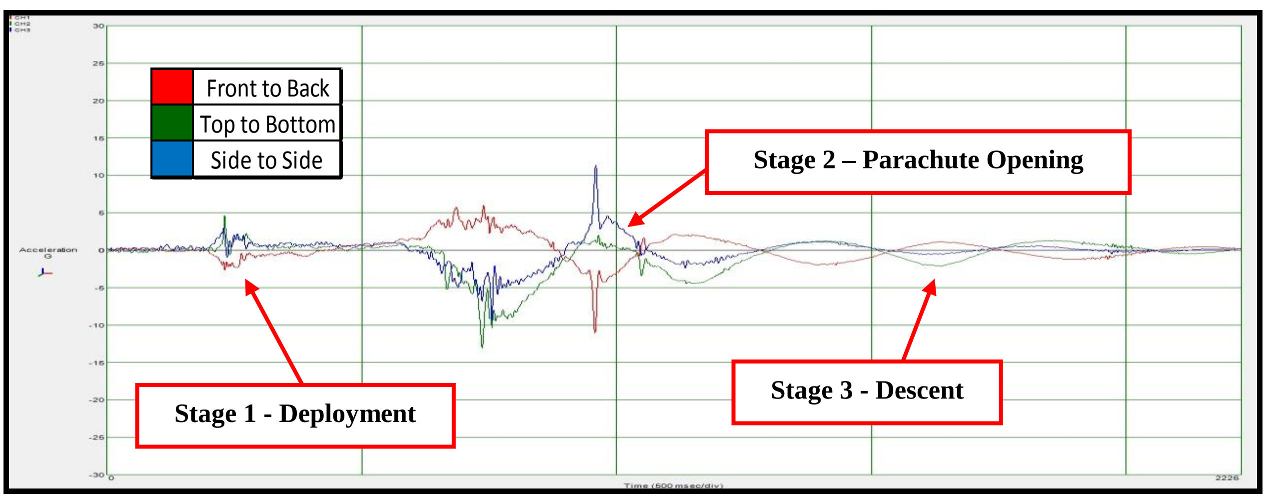

Figure 60. Shock Events Introduced by Parachute Deployment, Opening and Descent. (Load 4 - LV)

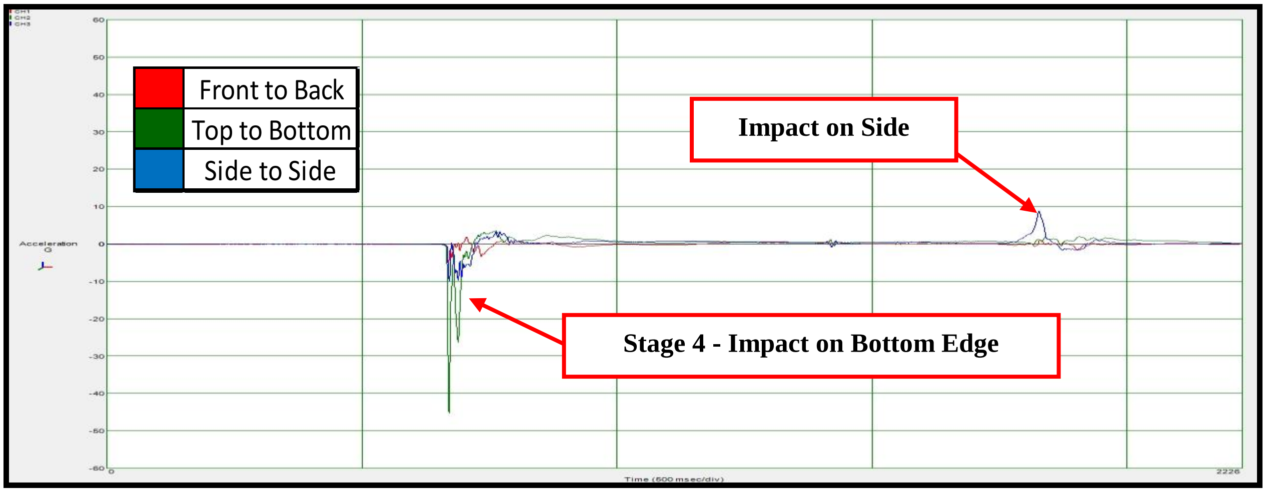

Figure 61. Shock Events Introduced by Ground Impact (load 4 - LV).

6.3.3.1 Recovery of Unit Loads

After each pass and associated delivery the test units were inspected for damage and to document the landing conditions. The loads were identified, inspected and loaded on transport vehicles and returned to the warehouse for more detailed visual inspection.

In preparation for a drop the cargo door and ramp of the aircraft was opened and a drogue parachute released. The aircraft descended to the drop altitude (typically under 2 m). Once the drop plane reached the desired drop point, the braking parachutes for the load were released and they were extracted from the aircraft by the drogue chute and the drop load was released (retaining straps cut). The braking parachutes pulled the load from the aircraft and brought it to a stop on the ground within the drop zone. The main parachutes were sized to stop the movement of the load sliding on the ground within the required space, and were not intended to control the descent of the load to the ground. Cushioning of the load was accomplished by the pallet and the material between the pallet and the load. Once the delivery was accomplished, the pilot ascended to a normal altitude and returned to base. A photograph of the actual drop of high velocity aerial delivery system (6 unit loads) is shown in Figure 62

Figure 62. November 15th Drop of High Velocity Aerial Delivery System (6 Unit Loads) Using Standard 26' Ring Slot Cargo Parachute Systems.

Figure 63. High Velocity Impact of MRE Rations.

Figure 63 highlights the drop zone used during the aerial delivery demonstration. The test items in the figure were from the high velocity samples which were dropped as a set of six rigged loads. The area of impact consisted of a grassy field with the majority of the loads impacting in a vertical position upon solid ground. Two loads from the high velocity drops landed in or nearby the small watering hole, located in the center of the drop zone.

Figure 64. MRE Unit Load #4 After Low Velocity Aerial Delivery Trial

Figure 64 highlights the unit load configuration for 48-case load of MRE rations, containers, layers of paper honeycomb energy absorbing material, wooden pallet and aerial delivery system employing a G-12 E Cargo Parachute.

6.3.3.2 **Inspection Air Drop**

After the free drop trials each fiberboard container and associated ration packaging (control and nanocomposite packaging of the meal bag, retort pouch, and non-retort pouch) were inspected for any signs of physical damage that may have occurred during transport, handling or delivery. A 100% inspection of the sixty test samples was conducted and the defects were compiled and organized into major categories to help identify failure modes and survivability rates of each system. The MRE inspection followed inspection procedures listed in ACR-M-032. Failure rates were recorded for each sample set and pictures of representative failures were documented.

6.3.3.3 Container inspection results

Visual package inspection was an important part of the demonstration and evaluation process. The visual inspections were performed manually by two inspectors to ensure overall integrity of the samples. NSRDEC inspectors were properly trained to recognize specific defect types, material variations, and failure modes of ration packaging.

A careful external visual examination of primary and secondary packaging is the primary means of identifying container defects. During this inspection two primary packages that included the retort and non-retort pouch were inspected for defects along with the inspection of the secondary package, meal bag. Additionally the MRE shipping container was also inspected for major failures caused by the ground impact.

The inspection process for the retort pouch focused on three main areas of the packaging which included the 3-sided preformed seal and edge, the manufactured seal that encloses the filled package and the body of the pouch including the area between all four seals. In most cases the failure of the retort pouch came from seal failure of the manufactured seals due to high levels of internal pressure and product movement.

The inspection process for the non-retort pretzel pouch also focused on three main areas of the packaging which included the 3-sided preformed seal and edge, the manufactured seal that encloses the filled package and the body of the pouch including the area between all four seals on both sides. In most cases the failure of the non-retort pouch came from crushed or broken product due to high levels of compression. This defect is categorized as a major defect and also caused high instances of failure in the existing foil based pouch, creating multiple pinholes in the body of the pouch. The pinholes were created by the combination of high compressive forces at impact and the salt found on the pretzels, which would often puncture the foil based packaging. Failures in the nanocomposite packaging had no accounts of pinholes and were found to be more resistant to puncture over the control package.

The following quality assurance criteria, utilizing ANSI/ASQ Z1.4, Sampling Procedures and Tables for Inspection by Attributes, are required. Unless otherwise specified, single sampling plans indicated in ANSI/ASQ Z1.4 was utilized. The assembled rations were inspected for the defects. The lot size is expressed in rations and one sample unit consisted of a meal bag, retort pouch and non-. The inspection level shall be S-4 and the AQL, expressed in terms of defects per hundred units, shall be 2.5 for major defects and 4.0 for minor defects. A minimum of 50 samples shall be examined for critical defects.

Three defect categories listed as critical, major and minor are defined in the assembly contract requirements (ACR-M-032) for assembled rations and provide the criteria for acceptance or rejection of a sample lot. The critical defect category includes non-conforming samples that contain a defect that judgment and experience indicate would result in hazardous or unsafe conditions for individuals using, maintaining, or depending on the item; or a defect that judgment and experience indicate is likely to prevent the performance of the major end item, i.e. consumption of the ration. The major defect category includes non-conforming samples that contain a defect, other than critical, that is likely to result in failure, or to reduce materially the usability of the unit of product for its intended purpose. The minor defect category includes non-conforming samples that contain a defect that is not likely to reduce materially the usability of the unit product for its intended purpose, or is a departure from established standards having little bearing on the effective use or operation of the unit.

The inspection process for the meal bag focused on three main areas of the packaging which included the peelable seal and edge, the manufactured seal that encloses the assembled ration and the body of the pouch including the area between both seals. In most cases the failure of the meal bag came from seal failure of the peelable seal and pinholes/tearing of the meal bag due to high levels of compression

6.3.3.4 Low Velocity Results (Loads 4, 5, and 6)

During the meal bag packaging inspection of the low velocity airdrop samples (loads 4, 5, and 6), three types of defects were identified which included pinholes, failure of the peelable seal, and stress whitening. The control meal bag was found to have two types of minor defects in the packaging which included pin holing and bursting at the peelable seal. Failure of the 11 mil film structure through pin holing was the most common defect found in the control samples. Incidents of pinhole failure were highest in load 4 with 6.3% of samples showing this type of package defect. Failure of the peelable seal was also identified as a minor defect with only one incidence of occurrence in load 4. Stress whitening of the material through mechanical stresses was also noted as a packaging defect but was not deemed critical to the overall performance of the meal bag structure. All samples inspected contained incidences of stress whitening but quantifying the rate of occurrence and degree of stressing was deemed too to quantify but was noted within the inspection sheets.

The High Velocity airdrops were conducted with standard High Velocity CDS procedures utilizing a static line deployed 26' Ring slot parachute at 2000' above ground level.

The typical rate of descent for Low Velocity CDS with the G-12 E cargo parachute is 26-28 FPS and High Velocity 70-90 fps. To compensate for the difference in rate of descent between high velocity and low velocity airdrop the CDS bundles utilize a standard energy dissipation material of cardboard Honeycomb. The energy dissipation material is cut in standard configurations for each type of airdrop being conducted. The shock events that were recorded could be attributed to either when the parachute opened or the impact of the load hitting the ground.

Table 68. Atmosphere Conditions at Maximum Altitude Reached During Aerial Delivery

Load	Recorder	Low Velocity	High Velocity	Temperature (ºF)	Humidity (%RH)	Altitude (ft)	Pressure (mbar)
1	Box 6		X	58.5	40.8	2943	910
2	Box 4		X	59.5	40.4	3068	905.8
3	Box 1		X	60.1	43.4	N/A	N/A
4	Box 1	X		50.4	45.9	N/A	N/A
5	Box 2	X		50.7	44.2	N/A	N/A
6	Box 3	X		50.6	43.4	3882	878.9
7	Box 3		X	59	40.9	3062	906
8	Box 2		X	60.1	40.5	N/A	N/A
9	Box 5		X	59.6	37.9	2925	910.6

Note: The Altitude and Pressure functions of the Savers9X30 in Box #1 & Box #2 were not enabled throughout the aerial delivery trials. The Temperature and Humidity data of these 2 boxes at maximum altitude is based on the estimated recorded event time.

Table 69. Atmosphere Conditions at Release.

Load	Recorder	Low Velocity	High Velocity	Temperature (ºF)	Humidity (%RH)	Altitude (ft)	Pressure (mbar)
1	Box 6		X	60.1	42	1491	959.8
2	Box 4		X	61.1	42.2	1554	957.6
3	Box 1		X	61.6	44.5	N/A	N/A
4	Box 1	X		52.8	48.6	N/A	N/A
5	Box 2	X		52.4	46.2	N/A	N/A
6	Box 3	X		51.6	45.8	2361	929.7
7	Box 3		X	60.4	42.5	1548	957.8
8	Box 2		X	61.1	41.5	N/A	N/A
9	Box 5		X	60.8	39.3	1583	956.8

Note: The Altitude and Pressure functions of the Savers9X30 in Box #1 & Box #2 were not enabled throughout the aerial delivery trials.

Table 70. Shock Events Introduced by Parachute Deployment

Load	Data Recorder	Low Velocity	High Velocity	Event	Orientation	Accel. (G's)	Duration (msec)	Delta V (mph)	Altitude (ft)	Pressure (mbar)
1	Box 6		X	Parachute deployment	No parachute deployment event recorded					
2	Box 4		X	Parachute deployment	Side	4.87	287	12.7	1236	968.8
					Top	5.81	361	21.3		
3	Box 1*		X	Parachute deployment	End	5.96	485	27.37	No data	No data
					Side	6.21	336	20.84		
				Load movement	End	6.28	13	5.6		
					Side	12.65	84	19.62		
4	Box 1*	X		Parachute deployment	End	5.98	366	20.67	No data	No data
					Top	13.05	232	30.4		
					Side	9.45	253	18.99		
				Load movement	End	11.11	122	9.41	No data	No data
					Side	11.4	106	8.86		
5	Box 2*	X		Parachute deployment	End	3.27	511	24.72	No data	No data
					Top	3.73	309	15.94		
				Load movement	End	6.2	159	13.68		
					Side	3.15	117	4.68		
				Load movement	End	4.83	176	11.33		
					Top	8.97	213	25.39		
6	Box 3	X		Parachute deployment	End	5.95	195	16.52	2104	938.5
					Side	7.09	193	18.88		
				Load movement	Bottom	13.57	214	36.07		
7	Box 3		X	Parachute deployment	No parachute deployment event recorded					
8	Box 2*		X	Parachute deployment	End	6.12	120	16.87	No data	No data
					Top	4.04	259	17.81		
					Side	3.75	204	9.36		
				Load movement	Side	6.64	518	24.92		
9	Box 5		X	Parachute deployment	End	7.64	307	19.07	1292	966.8
					Side	4.92	335	15.54		
				Load movement	Side	4.47	309	16.72		
					Top	5.11	309	19.52		

Note: The Altitude/Pressure functions of the Savers9X30 in Box 1 & 2 were not enabled during the aerial delivery trials.

Table71. Shock Events Introduced by Ground Impact

Load #	Recorder #	Low Velocity	High Velocity	Event	Orientation	Accel. (G's)	Duration (msec)	Delta V (mph)	Altitude (ft)	Pressure (mbar)
1	Box 6		X	Ground impact	Bottom	67.70	61.00	38.0	794	984.5
2	Box 4		X	Ground impact	Saver sheared off. No valid response recorded.					
3	Box 1*		X	Ground impact	Bottom	63.57	55.00	45.66	No data	No data
4	Box 1*	X		First ground impact	Bottom	45.23	13.00	13.32	No data	No data
					Side	9.98	8.00	6.48		
				Second ground impact	Side	8.75	76.00	5.16		
5	Box 2*	X		First ground impact	Bottom	15.66	76.00	12.71	No data	No data
				Second ground impact	End	22.29	20.00	4.86		
6	Box 3	X		First ground impact	Bottom	19.98	63.00	12.17	920	980.0
				Second ground impact	End	12.23	19.00	4.6		
					Side	6.87	19.00	1.53		

Note: The Altitude and Pressure functions of the Savers9X30 in Box #1 & Box #2 were not enabled throughout the aerial delivery trials.

Table 72. Shock Events Introduced by Ground Impact

Load #	Recorder #	Low Velocity	High Velocity	Event	Orientation	Accel. (G's)	Duration (msec)	Delta V (mph)	Altitude (ft)	Pressure (mbar)
7	Box 3		X	First ground impact	Bottom	100.00	6.00	45.53	738	986.5
				Second ground impact	End	70.88	19.00	11.43		
8	Box 2*		X	First ground impact	Bottom	100.00	48.00	63.90	No data	No data
				Second ground impact	End	65.10	7.00	5.05		
					Top	52.60	12.00	6.13		
					Side	100.00	8.00	10.77		
9	Box 5		X	Ground Impact	Bottom	78.64	47.00	44.33	797	984.4

Note: The Altitude and Pressure functions of the Savers9X30 in Box #1 & Box #2 were not enabled throughout the aerial delivery trials.

6.3.3.5 High Velocity Results (Loads 7, 8, and 9)

Figure 65 shows al the Meal Bag defects where pin holes defect was most prevalent on the control and nanocomposite meal bags. The control meal bags had more stress whitening defects that the nanocomposite bags for all the loads except load 8. There were also partial bursts in the controls in load 7 and load 8 for the controls, but none for nanocomposte. Load 9 for both the control and nanocomposite Meal Bags had bursts at the peelable seal.

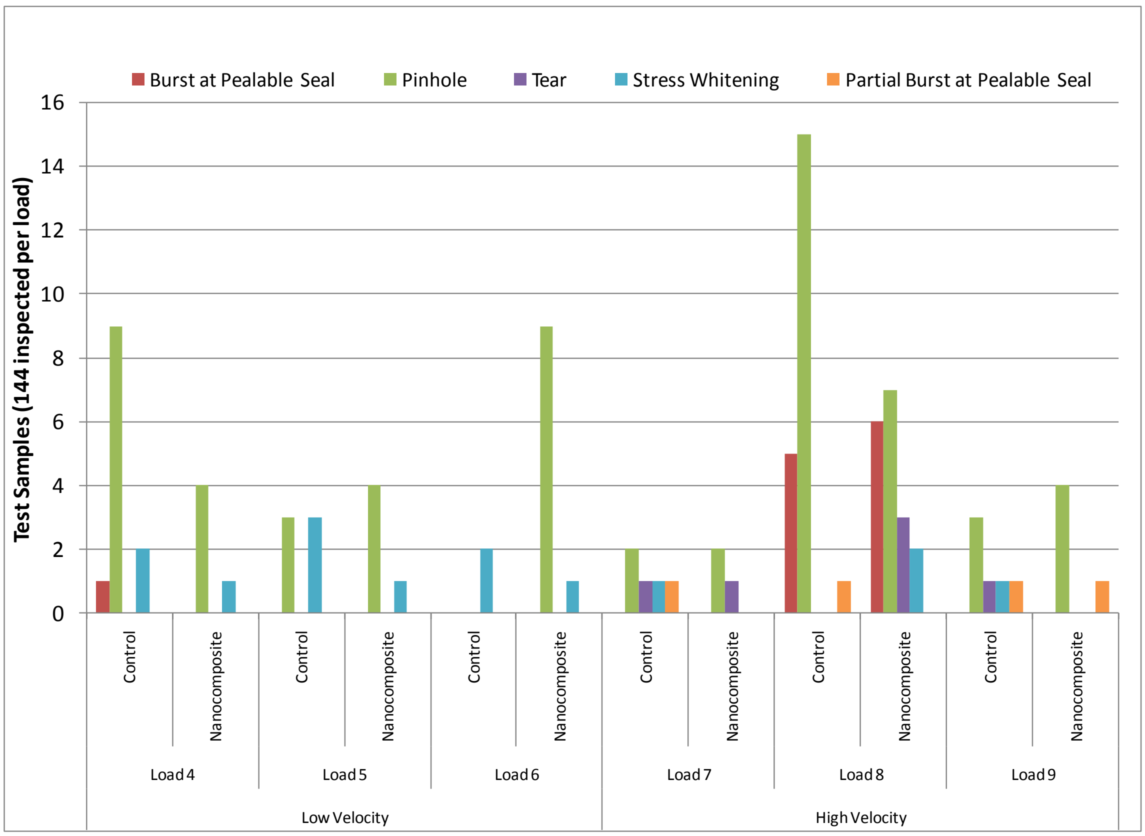

Figure 65 Meal Bag Defects by Type to include bursting at the peelable seal, pinhole, tearing, seal creep (i.e. partial bursting at the peelable seal) and stress whitening incidents.

Figure 66 shows the percentage of defects for each load. The nanocomposite Meal Bags showed less defects on three loads, slightly higher defects on two loads and the same number of defects for one load.

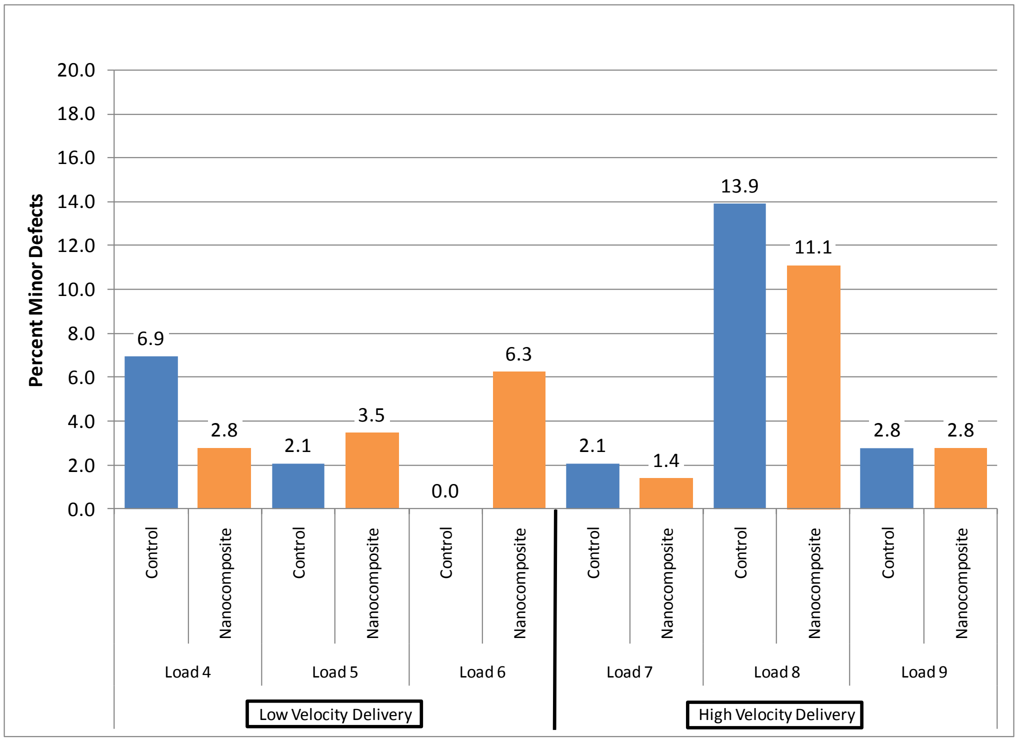

Figure 66. Percent of Minor Defects by Load.

6.3.3.6 Inspection

The inspection area used during material evaluations consisted of various working tables, auxiliary lighting and trash receptacle for obsolete rations. The type of inspection entails destruction inspection of the MRE ration and all of its components. The inspection areas are shown in Figure 68 and Figure 67.

Figure 67. Inspection Area During Visual Inspections of Individual Rations.

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Figure 68. Inspection Process

6. 3.3.8 **Fort Bliss Results** The assessment of the nanocomposite non-retort pouches filled with pretzels revealed no significant damage to the pouch structure. Destructive open package inspection was performed on 18 of the 144 cases in which six cases were randomly inspected from each of the three test pallets. The destructive package inspections revealed defects in only the nanocomposite retort pouches yielding a failure rate of 5.6% of the samples inspected. The examination of the penne pasta nanocomposite retort pouch showed that the test samples had only slightly higher failure rates at the manufactured seal area in comparison to the existing retort pouches and yielded a failure rate below 15% which is the set limit under the project goals. This transportation study completes an initial effort to analyze the distribution system and its impact on military rations and is part of an ongoing study to ensure all developmental packaging designs meet military performance requirements during transport and storage operations.

Figure 69 Stress Whitening and Failure of Manufactured Seal Resulting in Product Exposure (C GL/KN)

6.3.3.9 Results Fort Richardson: The results shown are based on visual inspections of the MRE test samples that included existing control systems, nanocomposite meal bags, retort pouches and non-retort pouches. From each sample lot seven cases from each material type were inspected with four rations from each case inspected by VETCOM and the remaining eight rations from each case inspected by NSRDEC engineers. The cases were inspected by both VETCOM inspectors and NSRDEC engineers with a focus on examining the food quality and packaging integrity of the prototype and control systems. The VETCOM inspectors examined the food quality to include overall taste, odor and appearance. In addition to examining the food items, VETCOM inspectors also examined the existing packaging controls as well as the prototype nanocomposite packaging. NSRDEC engineers focused on examining solely the packaging elements of the combat rations with a focus on identifying critical failures in the packaging that may reduce shelf life of the MRE components or inadequately protect the ration items.

The meal bags that were inspected for this study showed eight types of failure or damage to the packaging that may reduce the overall effectiveness of the package and system as a whole in protecting the ration items. In addition to the eight types of failures some meal bags were categorized as having no visible damage (NVD) to the package. Upon visual inspection these test samples were found to have no major signs of failure such as a burst seal or torn/punctured film that exposes the internal components to the external environment. These samples may still have had failures inherent in their package but were not noticed at the time of inspection and may also have minor flex whitening or creases within the body of the meal bag. One type of failure was stress marks or punctures from the corner of the carton (ctn) from the main entrée. When packed on the outside of the carton may often puncture or stress the out meal bag due to over packing of the internal components and limited space within the secondary shipping container. Stress marks at primarily the peelable seal were also noted as well as stresses at the final manufactured seal as well. These marks are often seen as small tears or partial pealing of the seal often from internal pressure within the meal bag.

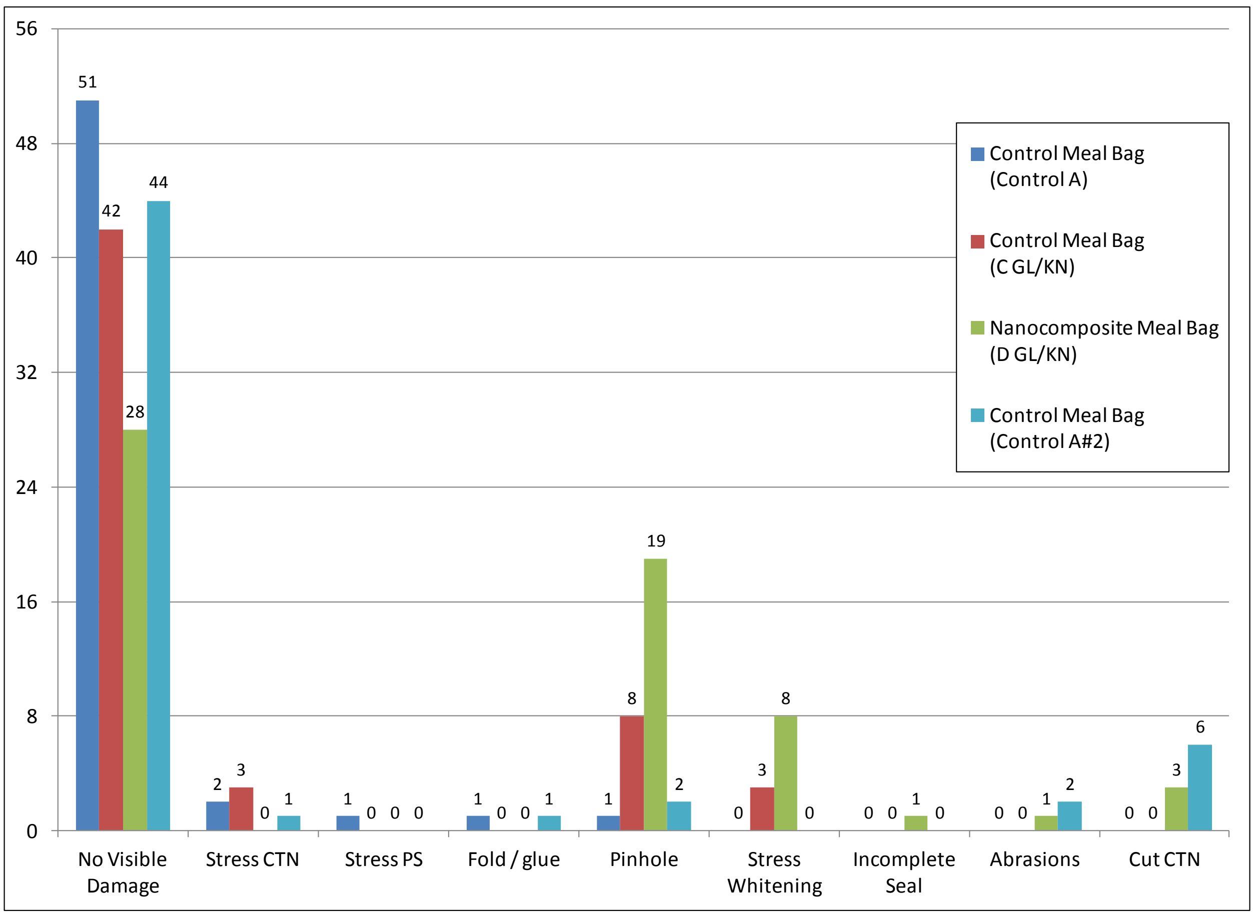

Figure 70. Failure Results of Meal Bag Test Samples

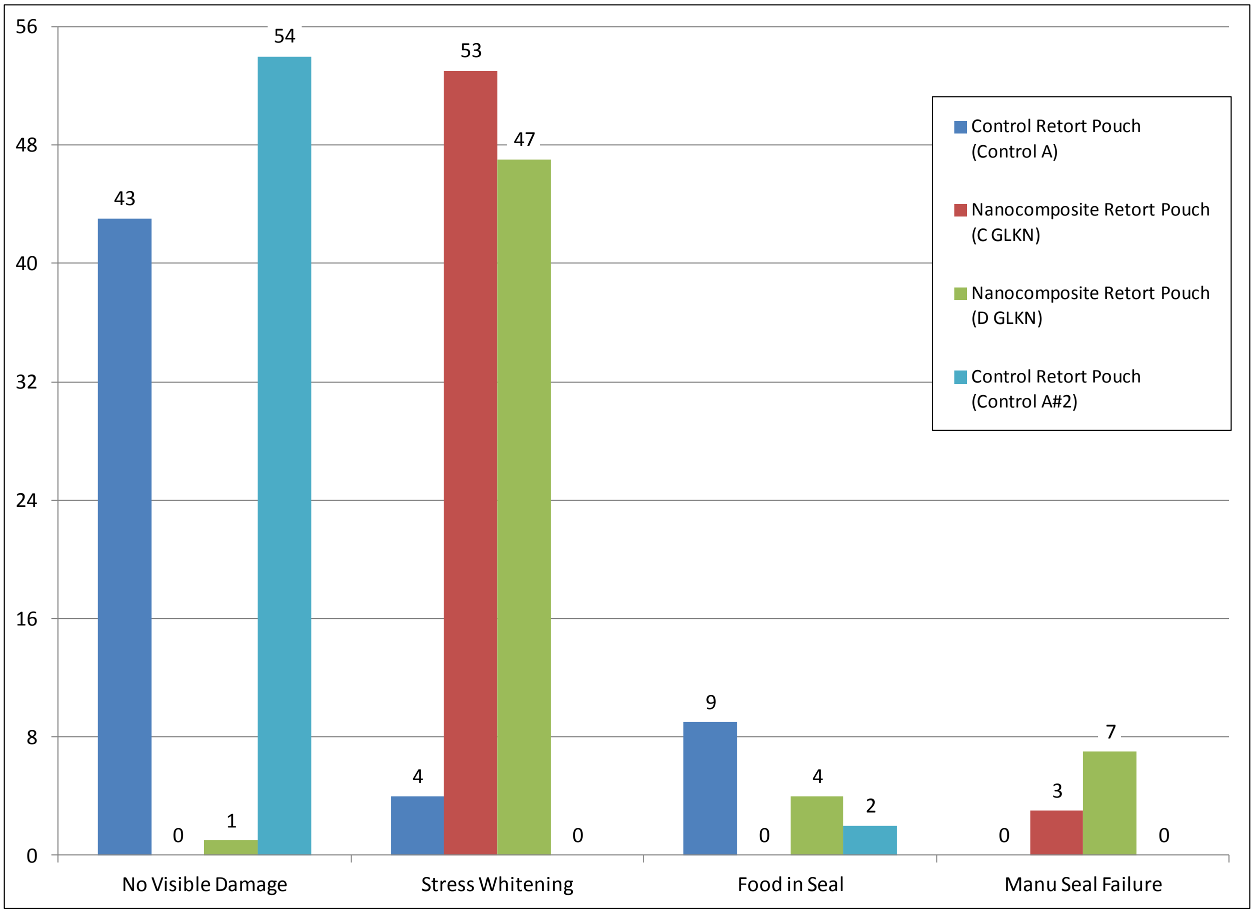

Figure 71. Failure Results of Retort Pouch Test Samples

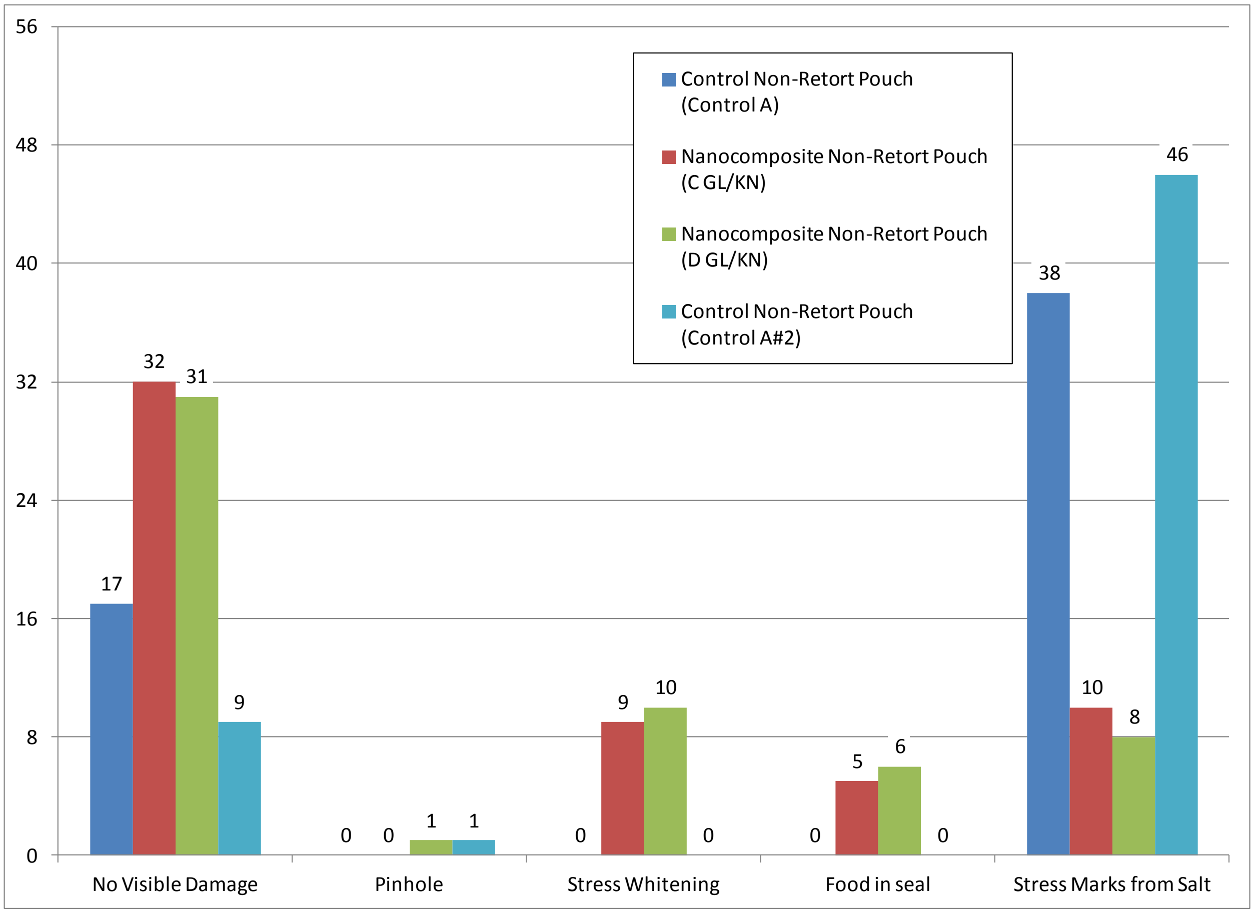

Figure 72. . Failure Results of Non-Retort Pouch Test Samples

Figure 73. Damage Marks from Salted Pretzels (Control Pretzel Pouch).

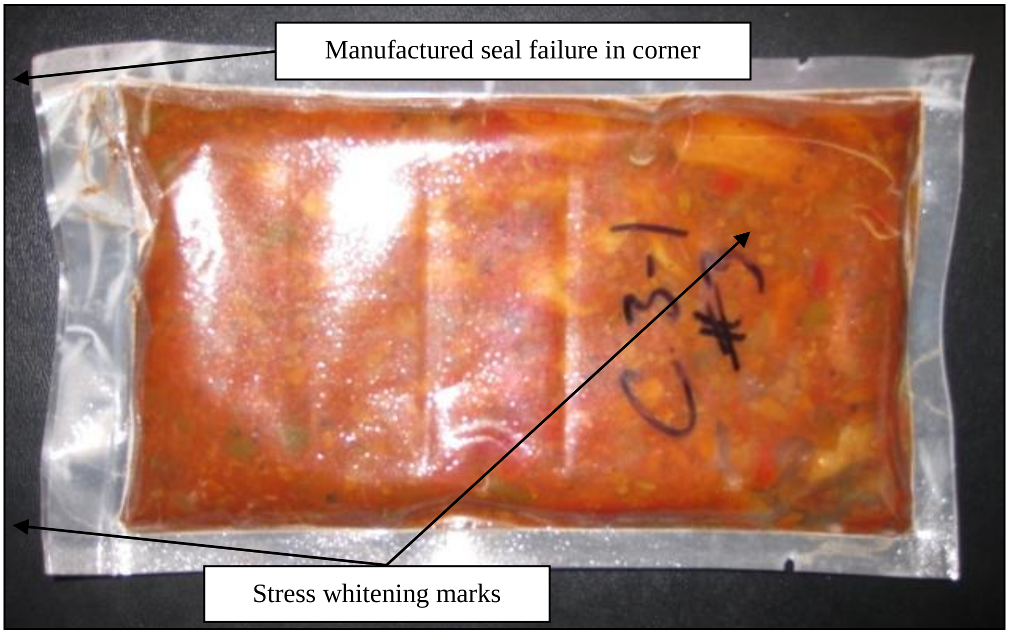

Figure 74. Stress Whitening and Failure of Manufactured Seal Resulting in Product Exposure (C GL/KN 3-1-3)

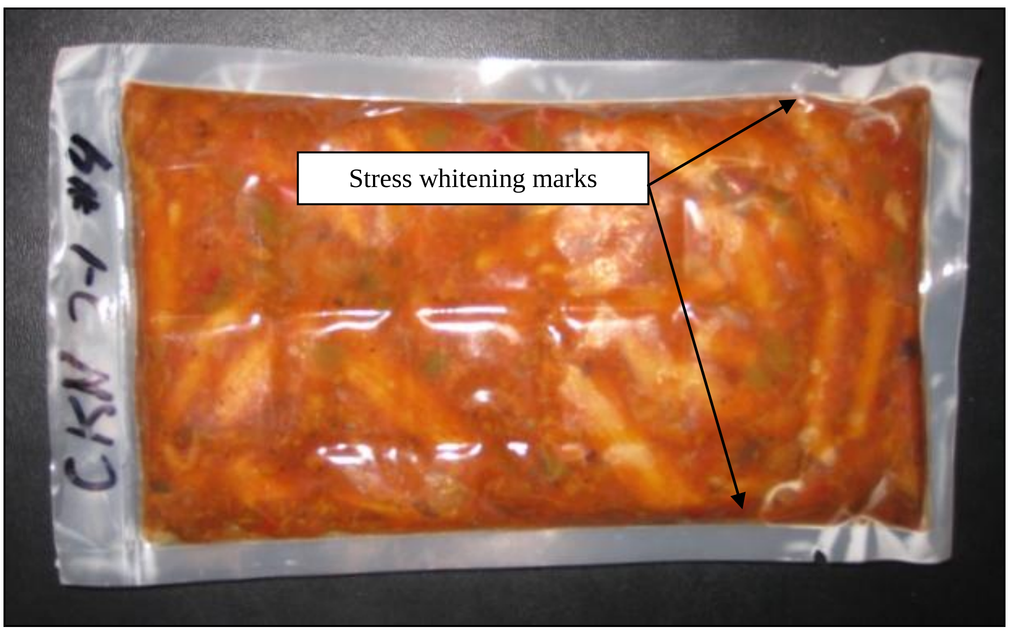

Figure 75. Stress Whitening of Prototype Retort Pouch (C KN 2-1-1)

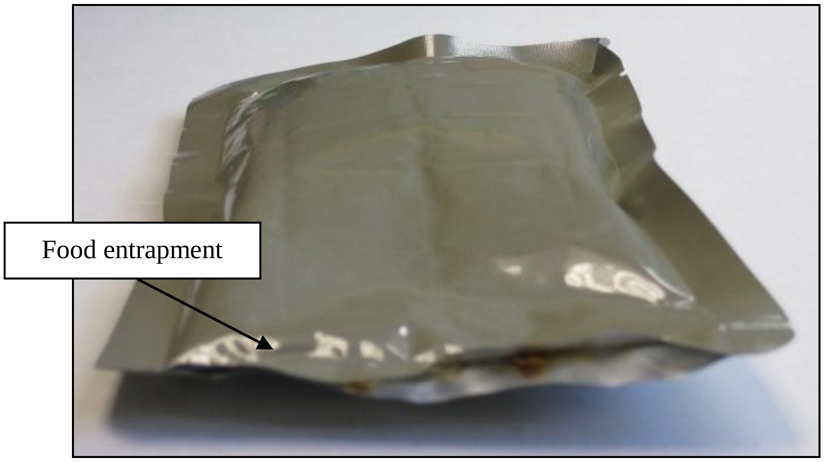

Figure 76. Food Entrapment in Manufactured Seal Resulting in Weakened Seal or Failure.

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6.3.4 Ease of Processing, Filling and Packing the Nanocomposite Ration Packaging

The Qualitative Performance Objectives are the ease of processing and packaging. This is important as the pouches and bags need to be fabricated on the converter's commercially available equipment. All of the co packers must be able to adapt to this new packaging and gain acceptability. The co packers provided feedback on the filling and the packing of the MREs into the fiberboard shipping containers. Also, the co packers did an end item inspection and issued a certificate of conformance for the Board of Veterinary to review. A success criterion does depend on the acceptability and conformance.

The nanocomposite packaging does not affect the penne pasta, but it does affect the pretzels. There is a moisture migration factor present in the pretzels in the nanocomposite package that is not present in the pretzel control. When breaded products are stored in cooler temperatures, there is a staling effect. Bound water may be released and/or moisture migration may travel into the package through a tortuous path in the nanocomposite materials due to cold temperature influence on the materials. To the consumer, the pretzel product in the nanocomposite package is disliked on average (in the negative zone of the LAM scale).

6.3.5 Reduce Disposal Waste

This objective is to reduce the amount of solid disposal waste for the military with the nanocomposite Meal Bag. Reducing the overall waste in the field, due to Meal Bag weight reduction, is one of the most important performance objectives. The nanocomposite Meal Bags are thinner than the existing bag and weigh less. The metric is the weight of waste resulting from Meal Bags in pounds. The data requirement is determining the weight of the individual nanocomposite Meal Bag. A cumulative waste value was calculated by summing the individual weights of the Meal Bag waste. The success criteria are that each bag weighs less than 0.075 lb. which is the weight of the existing Meal Bag.

6.3.6 Reduce Polymer (Resin) Amount During Manufacturing

This objective addresses the reduction of polymer used during manufacturing of the Meal Bags through the production of a thinner Meal Bag. The metric was the weight in pounds of plastic

Table 73used for the production trial of a predetermined quantity of Meal Bags. The data required would be the amount of plastic for the production trial. The success criterion is that the amount of plastic per Meal Bag would be less than 0.075 lbs.

7.0 COST ASSESSMENT

This section provides sufficient cost information for implementing nanocomposite polymeric packaging and its life-cycle costs as compared to the currently foil food pouches. In addition, discussion of the cost benefit of the technology is presented.

7.1 COST MODEL

This section discussed the methodology used in the cost assessment which is based off material weight and cost. The cost of the polymer can fluctuate with market prices, but the nanoparticle additives are more stable pricing. Polymeric structures with nanoparticles for food pouches for ration packaging can take the form of multiple layers with varying thicknesses. The price per pouch decreased as the number of polymeric layers in the film decrease.

Table 74. Retort Food Pouch Film Specification for Nanocomposite Packaging

Width, inches	70	60	50	40	35	30
Length, yards	250	292	350	438	500	583
MSI	630	630.72	630	630.72	630	629.64
2-ply	$ 375.55	$ 375.98	$ 375.55	$ 375.98	$ 375.55	$ 375.33
3-ply	$ 427.82	$ 428.31	$ 427.82	$ 428.31	$ 427.82	$ 427.58
4-ply	$ 486.41	$ 486.97	$ 486.41	$ 486.97	$ 486.41	$ 486.13
Cost Savings 3-ply over 4-ply	12%	12%	12%	12%	12%	12%
Cost Savings 2-ply over 4-ply	23%	23%	23%	23%	23%	23%
2 rolls each	$2,579.56	$ 2,582.50	$ 2,579.56	$ 2,582.50	$ 2,579.56	$ 2,578.08

Activity-based costing methodology for each element is listed. The cost elements associated with replacing the existing technology with the alternative technology are listed and discussed. The assembler, AmeriQual Packaging who buys the current meal bag and pouches were consulted with for prices of current items. A Meal Bag producer, Blackbird, and resin provider, Kuraray America was also consulted for prices, cost elements and a cost/benefit analysis.

Assumptions factored into cost/benefit calculations include less environmental burden for the meal bag since they can be recycled, but moreover, they use less material since they are thinner, , and there are potential reduced costs associated with a co-extruded pouch versus foil laminated pouch.

7.11 Processing and Pouch Formation Costs The first cost element is for the processing of the nanocomposite films and the trials to form the film into the meal bag and food pouches. The cost estimate was based on the cost of the labor and machine time. The data was presented as a cost per Meal Bag in comparison to the current components. The manufacturing costs of the new technology are one of the most important costs for the life cycle analysis. The new technology does not laminate with aluminum foil, but laminates polymers together for the non-retort and retort pouches.

7.12 Resin (Polymer) For Manufacturing This element address the amount of resin that is needed for the production of the meal bags and the food pouches. Resin amounts were less than the existing technology especially for the meal bag. Also, the cost of using nanoparticles in the Meal Bags, and the barrier coated materials for replacement of the foil in the retort and non-retort pouch is addressed in this element. Market resins prices at time of test were used to determine cost.

7.13 Filling/Sealing Process of Food Pouches. This element addresses how the line speed was affected by using these new packaging materials. Labor and time for filling and sealing need to be recorded as this could influence the processing costs. Material scrap should also be accounted for during the fill and seal to compare to existing technology.

7.14 Disposal Costs This element is disposal costs to determine the amount of waste to be disposed and the costs associated with that. This was based from the waste characterization. This data was scaled up depending on the procurement of MREs and this was also compared to the existing MRE packaging. Cost savings due to recycling of bags were also addressed here.

7.15 Shipping and Handling Costs This element is the shipping and handling costs. Data was obtained on all the costs incurred for shipping the pallets of MREs throughout the demonstration. The costs were compared to the existing MREs. The nanocomposite packaging could potentially cost less to ship due to the lighter packaging.

7.16 Soldier training The element of soldier training is needed to educate the soldier on the new packaging and possible disposal options (if recyclable). This is important but perhaps somewhat invisible since the new packaging may not appear significantly different than the current packaging. This has life cycle costs associated with it for all soldiers would need to be informed on the sorting of this new packaging for disposal

7.2 COST ANALYSIS AND COMPARISON

This section provides realistic estimates for the costs of the alternative technology when implemented operationally.
Initiatives focused on materials research and packaging optimization through down gauging, material selection and packaging design have demonstrated that MRE waste reduction efforts can yield substantial savings in direct material cost and additional reductions in overall life cycle sustainment costs. Transitioning new material solutions and packaging designs can create annual savings of approximately $5 million (use Estimated Weight Savings over 1 year – 452,936 by

reducing packaging in the following ways: reducing thickness of the meal bag; optimizing polymeric structures to better meet military stringent performance requirements and eliminating redundant or excess packaging for individual combat rations.

By reducing the thickness of the meal bag from 11 mil to 7 mil, DoD would be able to reduce packaging requirements by 36.3% or equivalent to approximately 450,000 pounds or 226 tons (short, US) of packaging material over one procurement cycle of one year. In the first three years of integration, DoD can potentially save an estimated $2.8 million (i.e. use the weight savings of 1,358,809 lbs over three years, multiply by $/lb of control packaging and then subtract the cost of the nanocomposite material again using the 1,358,809 multiplied by the $/lb of the nano material for total packaging material costs.

The optimization of the MRE meal bag and component packaging is considered a high payoff effort that would have a tremendous impact on the subsistence supply chain. The reduction in packaging impacts operations across the supply chain and impact critical activities such as raw materials sourcing, packaging procurement, manufacturing, ration assembly and distribution activities. Logistics operations are also be impacted by the reduction of packaging materials with transformations seen in transport, storage and disposal operations. Sourcing of the raw material and packaging components is the activity most affected by the change in packaging material. Developmental efforts have created a meal bag that has reduced thickness and an overall weight reduction when compared to the AmeriQual meal bag. The AmeriQual meal bag has a thickness of approximately 11 mils thick, while the nanocomposite meal bag has a reduced thickness of 7 mils in thickness. for the meal bag has created a comparable meal bag with reduced thickness, down to 7 mils thick and an overall weight reduction when compared to the AmeriQual meal bag that is of similar size but , which is estimated to eliminate 91 shipments from the ration assemblers to storage depots and provide additional savings as they are redistributed throughout the U.S. and abroad. Additionally, large scale savings in material usage were also result from this effort, for example, polymeric case banding material used to seal MRE containers were reduced by six inches per container, creating an annual savings of 1.1M linear feet of polymeric banding material. The weight reduction from this change would add up to approximately 321,000 lbs per procurement cycle. Design changes proposed for the meal bag alone would create an estimated 0.046 pounds reduction in packaging film per meal, and based on an average procurement of 40M rations this change would eliminate approximately 1.2M pounds of plastic packaging from the waste stream. The PlasticsExchange.com website recently estimated linear low density polyethylene film at $0.8/lb, is projected to gradually increase as unrefined petroleum prices continue to escalate. At this commodity price, an estimated savings of $1.3M can be realized in the first year of implementation with the proposed reduction in material. In addition to logistics improvements, the individual Warfighter would also benefit from a reduction in overall weight and size, as a more compact ration would be easier to pack and carry and would reduce unnecessary packaging waste generated in the field. The reduction in waste would also result in fuel, time and cost savings associated with backhauling waste and disposing of it discarded packaging material, creating an environmental advantage as well.

AmriQual Data Existing Pouches
Retort 8 OUNCE preformed LINEAL TEAR $.0838
Non retort - SNACK POUCH $.037

Kuraray reported that the pricing for these nanocomposite retort pouches is: $0.047-059 per pouch for retort.

Here is the calculation for the Meal bag utilizing the current material and the nanocomposite material:

Bag Length x Width x thickness (gauge in mils) divided by 15 divided by 1000 times bags per case was equal net pounds per case.

So, for a MRE™ bag, 15"x8.5" x 11 mil equals 1402.5 divided by 15 equals 93.5 divided by 1000 equals .0935 x 11 equals about 1 pound.

There are approximately 11bags per 1 pound. for the control meal bag

For the MRE nanocomposite meal bag performing the same calculation with a 7 mil bag, there would be about 16 meal bags equal to about 1 lb. However, the added cost of the nanoparticles must be added to the cost.

The entire cost element can be used to estimate the life-cycle costs for implementing and operating the demonstrated nanotechnology. The following were considered: (1) facility capital cost which is not necessary for the nanocomposite packaging since there is already many manufacturers with the existing equipment to make the film and pouches simultaneously , (2) There maybe start-up and operations and maintenance costs, (3) There is no significant equipment replacement costs for manufacturing or assembly of the rations and (4) re-processing or re-application costs are not applicable. The time frame for the life-cycle cost estimate would begin once the pouches are produced.

Table 75. Cost Model for Nanocomposite Packaging for Military Rations

Cost Model for Nanocomposite Packaging for Military Rations

Cost Element	Data Tracked During the Demonstration	Cost of Current Technology	Cost of Nanocomposite Materials	% Difference
Material Cost ($/pouch)	Estimate the amount of material	**$0.084**	**$0.047-0.059**	**30-44%**
Processing and pouch formation costs (cost per pay)	Estimates made based on extrusion processing costs for demonstration	**$2500**	**$1800**	**28%**
Filling and packing costs	Labor and material required	**$15000**	**$15000**	**0%**
Storage costs	Estimates based on rate of consumable use during the field demonstration	NA	NA	0%
Facility waste characterization	Reduction in waste vs. baseline data with control MRE™	NA	From meal bag, 20% reduction	20%
Disposal costs	Frequency of required disposal Labor and material per disposal action(l$/year)	**$193,500**	**$135,500**	**30%**
Shipping and handling costs (per pallet)	Estimate based on components during demonstration	Shipping charge X	Shipping charge x minus 5 % less cost as result of lighter packaging	5%
Field Study	Estimate cost of the feeding, transportation, labor	**$10.000**	**$10,000**	**0**
Soldier training	Estimate of training costs for new	**$10,000 per year**	**$10,000 per year**	**0**

Calculating Net Present Value gives a profit/loss estimation of a project. It is the difference between the present value of cash outflows and cash inflows. By finding Net Present Value (NPV), the Army can decide whether an investment is worth the cost. A positive value indicates a profit, whereas a negative value indicates a loss. Anet-present-value calculations for implementation of the nanotechnology over different time periods needs to be evaluated.

The assessment of the life-cycle costs allows more pallets of MRE can be shipped due to the ease of packaging

8.0 IMPLEMENTATION ISSUES

The implementation of this technology depends on the results and completion of further performance testing of other food item. The decision process requires that upon completion and assuming positive results, there would be a decision brief presented to the JSORF summarizing the technology and the significant results. This JSORF board is voting members for the services to implement new items and technology for the Warfighter. If a positive decision is made, implementation of this technology can occur.

This technology has been briefed internally at NSRDED and to the CFREP Board to keep them abreast of this work.

Stakeholders include:

- Combat Rations Team of CFD
- FEST, CFD,
- Director, CFD
- Assemblers of rations (AmeriQual, Sopacko, Wornick) who have the choice to purchase these types of pouches for the rations,
- Defense Logistics Agency Troop Command who contracts the assemblers and purchases ration items.

Recycling of the non-retort and retort pouches were the only success criteria that were not met, and this does not impact on transitioning the technology. Currently, there is no recycling infrastructure for the military in combat, so this would not be an issue for transitioning.

Currently, there are no environmental or worker safety regulations current or proposed that may impact the implementation of the technology. The manufacturing would be simplified with no lamination steps and manufacturing plants are set up to work with high barrier polymers and nanoparticles. The assembly trials in the demonstration and validation execution discussed any safety regulations that would need to be addressed.

For procurement issues, there is no special equipment required for implemtation, as DLA would be procuring an award to the assembler who would then buy pouches to comply with the specifications in the contract. The ease of production and scale-up was verified in this demonstration/validation project. The pouches can easily be manufactured on a company's existing co-extrusion equipment. The polymeric nanocomposite pouches for this demonstration were specific to a certain company providing the nanoparticles and their polymeric materials. This effort wants to expand the transition to include any all polymeric high barrier structure that can meet the military requirements. In the technology transfer efforts and the ongoing work after this study, we have expanded the non-retort and retort pouch to other structures. The specifications for the military need to be modified to state the required performance requirements. This all polymeric pouch can replace a foil laminated pouch and this needs to be reflected in the specifications. In addition, for this demonstration project, only one of the three assemblers, AmeriQual Packaging, participated in the study. NSRDEC has been working with other assemblers to educate them on the work and the potential pouches.

There is intellectual property for the nanocomposite structures within the suppliers of the material, but this should not affect the transition since the assembler just buy pouches that meet a certain performance specification.

This nanocomposite polymeric packaging for the MRE, can be expanded to the group rations within the Army and also be considered for other services.

Table 76 shows ongoing work currently with other food products to evaluate in the nanocomposite package for non-retort and retort foods. If upon completion of a six month storage study with these materials the results are successful, this technology would be ready to implement. The Army is also investigating other sterilization methods besides retort for the future, so these food items are currently being evaluated also with the other methods.

Table 76. Products for Accelerated Storage Study

Retort / Non-retort	Product Category	Proposed Food Item
Retort	High acid	Spicy Penne Pasta
Retort	Low acid	Pork Sausage with Crème Sauce
Retort	Water**	Water
Non-retort	High Moisture	Filled/baked item, sandwich, cinnamon bun
Non-retort	Low Moisture	Snacks (i.e. pretzals)
Non-retort	High Fat	Peanuts, pound cake
Non-retort	Full Vacuum	Peanuts, crackers
Non-retort	With O2 Sachet	Nut raisin mix with M&M's
Non-retort	Hot Fill	Cheese and/or peanut butter speads

**Water (retorted at 275F for 90 minutes) to test package integrity under stressful retort conditions and to simulate worst case product rough handling tests.

*** Optional products may be optimally selected based on whether preformed pouches or films that can be formed on horizontal form fill seal equipment are developed

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